TMS320C2x User's Guide

1604907-9761 revision C
January 1993

Read This First

About This Manual

The purpose of this user's guide is to serve as a reference book for the TMS320C2x digital signal processors. Chapters 2 through 6 provide specific information about the architecture and operation of the devices. Appendices A through E furnish electrical specifications and mechanical data.

How to Use This Manual

This document contains the following chapters:

Chapter 1 **Introduction**
Description and key features of the TMS320C2x generation of digital signal processors.

Chapter 2 **Pinouts and Signal Descriptions**
Package drawings for TMS320C2x devices. Functional listings of the signals, their pin locations, and descriptions.

Chapter 3 **Architecture**
TMS320C2x design description, hardware components, and device operation. Functional block diagram and internal hardware summary table.

Chapter 4 **Assembly Language Instructions**
Addressing modes and format descriptions. Instruction set summary listed according to function. Alphabetized individual instruction descriptions with examples.

Chapter 5 **Software Applications**
Software application examples for the use of various TMS320C2x instruction set features.

Chapter 6 **Hardware Applications**
Hardware design techniques and application examples for interfacing to memories, peripherals, or other microcomputers/microprocessors. XDS design considerations. System applications.

Eleven appendices are included to provide additional information.

Appendix A **TMS320C25 Digital Signal Processor**
Electrical specifications, timing, and mechanical data for the TMS320C25 devices.

Appendix B **TMS320C26 Digital Signal Processor**
Data sheet information for the TMS320C26 digital signal processor.

Appendix C **TMS320C28 Digital Signal Processor**
Data sheet information for the TMS320C28 digital signal processor.

Appendix D **SMJ320C2x Digital Signal Processors**
Data sheet information for the SMJ320C2x digital signal processors family.

Appendix E **Instruction Cycle Timings**
Listings of the number of cycles for an instruction to execute in a given memory configuration on the TMS320C25.

Appendix F **TMS320E25 EPROM Programming**
Programming hardware description and methodology.

Appendix G **Analog Interface Peripherals and Applications**
Discussion of various analog input/output devices that interface directly to TMS320 DSPs and their applications.

Appendix H **Memories**, **Analog Converters**, **Sockets**, **and Crystals**
Listings of the TI memories, analog converters, and sockets available to support the TMS320C2x devices in DSP applications. Crystal specifications and vendors.

Appendix I **ROM Codes**
Discussion of ROM codes (mask options) and the procedure for implementation.

Appendix J **Quality and Reliability**
Discussion of Texas Instruments quality and reliability criteria for evaluating performance.

Appendix K **Development Support**
Listings of the hardware and software available to support the TMS320C2x devices.

Style and Symbol Conventions

This document uses the following conventions.

- Program listings, program examples, interactive displays, filenames, and symbol names are shown in a `special typeface` similar to a typewriter's. Examples use a **`bold version`** of the special typeface for emphasis; interactive displays use a **`bold version`** of the special typeface to distinguish commands that you enter from items that the system displays (such as prompts, command output, error messages, etc.).

  Here is a sample program listing:

```
0011  0005  0001          .field    1, 2
0012  0005  0003          .field    3, 4
0013  0005  0006          .field    6, 3
0014  0006                .even
```

  Here is an example of a system prompt and a command that you might enter:

```
C:  csr –a /user/ti/simuboard/utilities
```

- In syntax descriptions, the instruction, command, or directive is in a **bold typeface** font and parameters are in an *italic typeface*. Portions of a syntax that are in **bold** should be entered as shown; portions of a syntax that are in *italics* describe the type of information that should be entered. Here is an example of a directive syntax:

  .asect "*section name***",** *address*

  .asect is the directive. This directive has two parameters, indicated by *section name* and *address*. When you use .asect, the first parameter must be an actual section name, enclosed in double quotes; the second parameter must be an address.

- Square brackets (**[** and **]**) identify an optional parameter. If you use an optional parameter, you specify the information within the brackets; you don't enter the brackets themselves. Here's an example of an instruction that has an optional parameter:

  LALK *16-bit constant* [*, shift*]

  The LALK instruction has two parameters. The first parameter, *16-bit constant*, is required. The second parameter, *shift*, is optional. As this syntax shows, if you use the optional second parameter, you must precede it with a comma.

  Square brackets are also used as part of the pathname specification for VMS pathnames; in this case, the brackets are actually part of the pathname (they are not optional).

```
{ * | *+ | *– }
```

  This provides three choices: `*`, `*+`, or `*–`.

- Braces ({ and }) indicate a list. The symbol **|** (read as *or*) separates items within the list. Here's an example of a list:

  Unless the list is enclosed in square brackets, you must choose one item from the list.

- Some directives can have a varying number of parameters. For example, the .byte directive can have up to 100 parameters. The syntax for this directive is:

  .byte *value*$_1$ [*, ... , value*$_n$]

  This syntax shows that .byte must have at least one value parameter, but you have the option of supplying additional value parameters, separated by commas.

Information about Cautions

This book may contain cautions. A **caution** describes a situation that could potentially damage your software or equipment.

The information in a caution is provided for your protection. Please read each caution carefully.

Related Documentation From Texas Instruments

General Digital Signal Processing:

Antoniou, Andreas, *Digital Filters: Analysis and Design*. New York, NY: McGraw-Hill Company, Inc., 1979.

Brigham, E. Oran, *The Fast Fourier Transform.* Englewood Cliffs, NJ: Prentice-Hall, Inc., 1974.

Burrus, C.S. and Parks, T.W., *DFT/FFT and Convolution Algorithms*. New York, NY: John Wiley and Sons, Inc., 1984.

Digital Signal Processing Applications with the TMS320 Family, Texas Instruments, 1986; Prentice-Hall, Inc., 1987.

Gold, Bernard and Rader, C.M., *Digital Processing of Signals*. New York, NY: McGraw-Hill Company, Inc., 1969.

Hamming, R.W., *Digital Filters*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1977.

IEEE ASSP DSP Committee (Editor), *Programs for Digital Signal Processing*. New York, NY: IEEE Press, 1979.

Jackson, Leland B., *Digital Filters and Signal Processing*. Hingham, MA: Kluwer Academic Publishers, 1986.

Jones, D.L. and Parks, T.W., *A Digital Signal Processing Laboratory Using the TMS32010*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1987.

Lim, Jae and Oppenheim, Alan V. (Editors), *Advanced Topics in Signal Processing*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1988.

Morris, L. Robert, *Digital Signal Processing Software*. Ottawa, Canada: Carleton University, 1983.

Oppenheim, Alan V. (Editor), *Applications of Digital Signal Processing*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1978.

Oppenheim, Alan V. and Schafer, R.W., *Digital Signal Processing*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1975.

Oppenheim, Alan V. and Willsky, A.N. with Young, I.T., *Signals and Systems*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1983.

Parks, T.W. and Burrus, C.S., *Digital Filter Design*. New York, NY: John Wiley and Sons, Inc., 1987.

Rabiner, Lawrence R., Gold and Bernard, *Theory and Application of Digital Signal Processing*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1975.

Treichler, J.R., Johnson, Jr., C.R. and Larimore, M.G., *A Practical Guide to Adaptive Filter Design*. New York, NY: John Wiley and Sons, Inc., 1987.

Speech:

Gray, A.H. and Markel, J.D., *Linear Prediction of Speech*. New York, NY: Springer-Verlag, 1976.

Jayant, N.S. and Noll, Peter, *Digital Coding of Waveforms*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1984.

Papamichalis, Panos, *Practical Approaches to Speech Coding*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1987.

Rabiner, Lawrence R. and Schafer, R.W., *Digital Processing of Speech Signals*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1978.

Image Processing:

Andrews, H.C. and Hunt, B.R., *Digital Image Restoration*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1977.

Gonzales, Rafael C. and Wintz, Paul, *Digital Image Processing*. Reading, MA: Addison-Wesley Publishing Company, Inc., 1977.

Pratt, William K., *Digital Image Processing*. New York, NY: John Wiley and Sons, 1978.

Digital Control Theory:

Jacquot, R., *Modern Digital Control Systems*. New York, NY: Marcel Dekker, Inc., 1981.

Katz, P., *Digital Control Using Microprocessors*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1981.

Kuo, B.C., *Digital Control Systems*. New York, NY: Holt, Reinholt and Winston, Inc., 1980.

Moroney, P., I*ssues in the Implementation of Digital Feedback Compensators*. Cambridge, MA: The MIT Press, 1983.

Phillips, C. and Nagle, H., *Digital Control System Analysis and Design*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1984.

Trademarks

MS, and *MS-DOS* are trademarks of Microsoft Corp.
VAX, VMS, and *Ultrix* are trademarks of Digital Equipment Corp.
PC-DOS is a trademark of International Business Machines Corp.
Sun 3 is a trademark of Sun Microsystems, Inc.
UNIX is a registered trademark of UNIX Systems Laboratories.
XDS is a trademark of Texas Instruments Incorporated.

If You Need Assistance. . .

If you want to. . .	**Do this. . .**
Request more information about Texas Instruments Digital Signal Processing (DSP) products	Write to: Texas Instruments Incorporated Market Communications Manager, MS 736 P.O. Box 1443 Houston, Texas 77251–1443
Order Texas Instruments documentation	Call the TI Literature Response Center: **(800) 477–8924**
Ask questions about product operation or report suspected problems	Call the DSP hotline: **(713) 274–2320**
Report mistakes in this document or any other TI documentation	Send your comments to: Texas Instruments Incorporated Technical Publications Manager, MS 702 P.O. Box 1443 Houston, Texas 77251–1443

Contents

1 Introduction 1-1
1.1 General Description 1-2
1.2 Key Features 1-6
1.3 Typical Applications 1-8

2 Pinouts and Signal Descriptions 2-1
2.1 TMS320C2x Pinouts 2-2
2.2 TMS320C2x Signal Descriptions 2-4

3 Architecture 3-1
3.1 Architectural Overview 3-2
3.2 Functional Block Diagram 3-6
3.3 Internal Hardware Summary 3-9
3.4 Memory Organization 3-12
3.4.1 Data Memory 3-12
3.4.2 Program Memory 3-12
3.4.3 TMS320C2x Memory Maps 3-15
3.4.4 TMS320C26 Memory Maps 3-16
3.4.5 Memory-Mapped Registers 3-22
3.4.6 Auxiliary Registers 3-22
3.4.7 Memory Addressing Modes 3-25
3.4.8 Memory-to-Memory Moves 3-27
3.5 Central Arithmetic Logic Unit (CALU) 3-28
3.5.1 Scaling Shifter 3-30
3.5.2 ALU and Accumulator 3-30
3.5.3 Multiplier, T and P Registers 3-32
3.6 System Control 3-35
3.6.1 Program Counter and Stack 3-35
3.6.2 Pipeline Operation 3-37
3.6.3 Reset 3-47
3.6.4 Status Registers 3-49
3.6.5 Timer Operation 3-52
3.6.6 Repeat Counter 3-53
3.6.7 Powerdown Modes (TMS320C25) 3-53
3.7 External Memory and I/O Interface 3-54
3.7.1 Memory Combinations 3-54
3.7.2 Internal Clock Timing Relationships 3-56
3.7.3 General-Purpose I/O Pins (BIO and XF) 3-56

3.8 Interrupts 3-59
3.8.1 Interrupt Operation 3-59
3.8.2 External Interrupt Interface 3-60
3.9 Serial Port 3-63
3.9.1 Transmit and Receive Operations 3-65
3.9.2 Timing and Framing Control 3-67
3.9.3 Burst-Mode Operation 3-68
3.9.4 Continuous Operation Using Frame Sync Pulses (TMS320C25) 3-69
3.9.5 Continuous Operation Without Frame Sync Pulses (TMS320C25) 3-71
3.9.6 Initialization of Continuous Operation Without Frame Sync Pulses 3-73
3.10 Multiprocessing and Direct Memory Access (DMA) 3-75
3.10.1 Synchronization 3-75
3.10.2 Global Memory 3-76
3.10.3 The Hold Function 3-78
3.11 General Description of the TMS320C26 3-82
3.12 General Description of the TMS320C28 3-83

4 Assembly Language Instructions 4-1
4.1 Memory Addressing Modes 4-2
4.1.1 Direct Addressing Mode 4-2
4.1.2 Indirect Addressing Mode 4-4
4.1.3 Immediate Addressing Mode 4-8
4.2 Instruction Set 4-11
4.2.1 Symbols and Abbreviations 4-11
4.2.2 Instruction Set Summary 4-13
4.3 Individual Instruction Descriptions 4-18

5 Software Applications 5-1
5.1 Processor Initialization 5-2
5.1.1 TMS320C26 Download/Bootstrapping Modes 5-6
5.2 Program Control 5-22
5.2.1 Subroutines 5-22
5.2.2 Software Stack 5-24
5.2.3 Timer Operation 5-25
5.2.4 Single-Instruction Loops 5-26
5.2.5 Computed GOTOs 5-28
5.3 Interrupt Service Routine 5-29
5.3.1 Context Switching 5-29
5.3.2 Interrupt Priority 5-32
5.4 Memory Management 5-33
5.4.1 Block Moves 5-33
5.4.2 Configuring On-Chip RAM 5-35
5.4.3 Using On-Chip RAM for Program Execution 5-38
5.5 Fundamental Logical and Arithmetic Operations 5-43
5.5.1 Status Register Effect on Data Processing 5-43
5.5.2 Bit Manipulation 5-44

5.6 Advanced Arithmetic Operations 5-46
5.6.1 Overflow Management 5-46
5.6.2 Scaling 5-47
5.6.3 Shifting Data 5-47
5.6.4 Moving Data 5-51
5.6.5 Multiplication 5-53
5.6.6 Division 5-57
5.6.7 Floating-Point Arithmetic 5-60
5.6.8 Indexed Addressing 5-62
5.6.9 Extended-Precision Arithmetic 5-62
5.7 Application-Oriented Operations 5-68
5.7.1 Companding 5-68
5.7.2 FIR/IIR Filtering 5-70
5.7.3 Adaptive Filtering 5-71
5.7.4 Fast Fourier Transforms (FFT) 5-75
5.7.5 PID Control 5-82

6 Hardware Applications 6-1
6.1 System Control Circuitry 6-2
6.1.1 Powerup Reset Circuit 6-2
6.1.2 Crystal Oscillator Circuit 6-5
6.1.3 User Target Design Considerations for the XDS 6-7
6.2 Interfacing Memories 6-11
6.2.1 Interfacing PROMs 6-12
6.2.2 Wait-State Generator 6-19
6.2.3 Interfacing EPROMs 6-22
6.2.4 Interfacing Static RAMs 6-26
6.2.5 Interface Timing Analysis 6-29
6.3 Direct Memory Access (DMA) 6-32
6.4 Global Memory 6-35
6.5 Interfacing Peripherals 6-37
6.5.1 Combo-Codec Interface 6-37
6.5.2 AIC Interface 6-40
6.5.3 Digital-to-Analog (D/A) Interface 6-42
6.5.4 Analog-to-Digital (A/D) Interface 6-43
6.5.5 I/O Ports 6-46
6.6 System Applications 6-48
6.6.1 Echo Cancellation 6-48
6.6.2 High-Speed Modem 6-48
6.6.3 Voice Coding 6-49
6.6.4 Graphics and Image Processing 6-50
6.6.5 High-Speed Control 6-51
6.6.6 Instrumentation and Numeric Processing 6-51

A TMS320C25 Digital Signal Processors A-1

B TMS320C26 Digital Signal Processor B-1

C TMS320C28 Digital Signal Processor C-1

D SMJ320C2x Digital Signal Processors D-1

E Instruction Cycle Timings E-1
E.1 TMS320C2x Instruction Cycle Timings E-2

F TMS320E25 EPROM Programming F-1
F.1 Using the EPROM Programmer Adapter Socket F-2
F.1.1 Supplying External Power F-2
F.2 Programming and Verification F-4
F.2.1 Erasure F-7
F.2.2 FAST Programming F-7
F.2.3 SNAP! Pulse Programming F-8
F.2.4 Program Verify F-8
F.2.5 Program Inhibit F-11
F.2.6 Read F-11
F.2.7 Output Disable F-11
F.3 EPROM Protection and Verification F-12
F.3.1 EPROM Protection F-12
F.3.2 How the RBIT Works F-14
F.3.3 Protect Verify F-15

G Analog Interface Peripherals and Applications G-1
G.1 Multimedia Applications G-2
G.1.1 System Design Considerations G-2
G.1.2 Multimedia-Related Devices G-4
G.2 Telecommunications Applications G-5
G.3 Dedicated Speech Synthesis Applications G-10
G.4 Servo Control/Disk Drive Applications G-12
G.5 Modem Applications G-15
G.6 Advanced Digital Electronics Applications for Consumers G-18

H Memories, Analog Converters, Sockets, and Crystals H-1
H.1 Memories and Analog Converters H-2
H.2 Sockets H-3
H.3 Crystals H-4

I ROM Codes I-1

J Quality and Reliability J-1
J.1 Reliability Stress Tests J-2

K Development Support K-1
K.1 Device and Development Support Tool Nomenclature K-2

Figures

1–1 TMS320 Device Evolution 1-3
2–1 TMS320C2x Pin Assignments 2-2
2–2 TMS320C28 Pin Assignments 2-3
3–1 TMS320C2x Simplified Block Diagram 3-3
3–2 TMS320C25/E25 Block Diagram 3-7
3–3 TMS320C26 Block Diagram 3-8
3–4 TMS320C2x On-Chip Data Memory 3-13
3–5 TMS320C26 On-Chip Data Memory 3-14
3–6 Comparison of Internal RAM Configured as Data Space 3-18
3–7 Comparison of Internal RAM Configured as Program Space 3-18
3–8 TMS320C2x Memory Maps 3-19
3–9 TMS320C26 Memory Maps 3-20
3–10 Indirect Auxiliary Register Addressing Example 3-23
3–11 Auxiliary Register File 3-24
3–12 Methods of Instruction Operand Addressing 3-26
3–13 Central Arithmetic Logic Unit (CALU), TMS320C2x 3-29
3–14 Examples of TMS320C25 Carry Bit Operation 3-31
3–15 Program Counter, Stack, and Related Hardware 3-35
3–16 Three-Level Pipeline Operation (TMS320C25) 3-38
3–17 Two-Level Pipeline Operation 3-38
3–18 TMS320C25 Standard Pipeline Operation 3-39
3–19 Pipeline Operation of ADD Followed by SACL 3-41
3–20 Pipeline Operation With Wait States 3-42
3–21 Pipeline With External Data Bus Conflict 3-43
3–22 Pipeline Operation of Branch to On-Chip RAM 3-44
3–23 Pipeline Operation of RET From On-Chip RAM 3-45
3–24 TMS320C2x Status Register Organization 3-49
3–25 TMS320C26 Status Register Organization 3-50
3–26 Timer Block Diagram 3-52
3–27 Four-Phase Clock 3-56
3–28 BIO Timing Diagram 3-57
3–29 External Flag Timing Diagram 3-58
3–30 Interrupt Mask Register (IMR) 3-60
3–31 Internal Interrupt Logic Diagram 3-61
3–32 Interrupt Timing Diagram (TMS320C25) 3-62
3–33 The DRR and DXR Registers 3-64
3–34 Serial Port Block Diagram 3-65
3–35 Serial Port Transmit Timing Diagram 3-66
3–36 Serial Port Receive Timing Diagram 3-67

3–37 Burst-Mode Serial Port Transmit Operation 3-68
3–38 Burst-Mode Serial Port Receive Operation 3-68
3–39 Byte-Mode DRR Operation (TMS320C25) 3-69
3–40 Serial Port Transmit Continuous Operation (FSM = 1) 3-70
3–41 Serial Port Receive Continuous Operation (FSM = 1) 3-70
3–42 Serial Port Transmit Continuous Operation (FSM = 0) 3-72
3–43 Serial Port Receive Continuous Operation (FSM = 0) 3-72
3–44 Continuous Transmit Operation Initialization 3-74
3–45 Continuous Receive Operation Initialization 3-74
3–46 Synchronization Timing Diagram (TMS320C25) 3-76
3–47 Global Memory Access Timing 3-77
3–48 TMS320C25 Hold Timing Diagram 3-80
4–1 Direct Addressing Block Diagram 4-3
4–2 Indirect Addressing Block Diagram 4-4
5–1 BIO–XF Handshake 5-7
5–2 Sequence for 8-Bit Transfers 5-8
5–3 Sequence for 16-Bit Transfers 5-8
5–4 Building LENGTH From STATUS and PROGRAM LENGTH Words 5-9
5–5 RS232 Connection to the TMS320C26 5-11
5–6 Sequence for RS232 Transfer (8 Data Bits Only) 5-13
5–7 Building LENGTH From STATUS and PROGRAM LENGTH Words 5-14
5–8 External Memory Byte Ordering 5-16
5–9 On-Chip RAM Configurations 5-36
5–10 MACD Operation 5-52
5–11 Execution Time vs. Number of Multiply-Accumulates (TMS320C25) 5-55
5–12 Program Memory vs. Number of Multiply-Accumulates 5-56
5–13 An In-Place DIT FFT With In-Order Outputs and Bit-Reversed Inputs 5-76
5–14 An In-Place DIT FFT With In-Order Inputs but Bit-Reversed Outputs 5-76
6–1 Powerup Reset Circuit 6-3
6–2 Voltage on TMS320C25 Reset Pin 6-4
6–3 Crystal Oscillator Circuit 6-5
6–4 Magnitude of Impedance of Oscillator LC Network 6-6
6–5 Direct Interface of TBP38L165-35 to TMS320C25 6-14
6–6 Interface Timing of TBP38L165-35 to TMS320C25 6-15
6–7 Interface of TBP38L165-35 to TMS320C25 6-17
6–8 Interface Timing of TBP38L165-35 to TMS320C25 (Address Decoding) 6-18
6–9 One Wait-State Memory Access Timing 6-20
6–10 Wait-State Generator Design 6-21
6–11 Wait-State Generator Timing 6-22
6–12 Interface of WS57C65F-12 to TMS320C25 6-23
6–13 Interface Timing of WS57C65F-12 to TMS320C25 6-24
6–14 Interface of TMS27C64-20 to TMS320C25 6-25
6–15 Interface Timing of TMS27C64-20 to TMS320C25 6-26
6–16 Interface of CY7C169-25 to TMS320C25 6-28
6–17 Interface Timing of CY7C169-25 to TMS320C25 6-29

6–18 Direct Memory Access Using a Master-Slave Configuration 6-33
6–19 Direct Memory Access in a PC Environment 6-34
6–20 Global Memory Communication 6-36
6–21 Interface of TMS320C25 to TCM29C16 Codec 6-38
6–22 Interface of TLC32040 to TMS320C2x 6-41
6–23 Synchronous Timing of TLC32040 to TMS320C2x 6-41
6–24 Asynchronous Timing of TLC32040 to TMS320C2x 6-42
6–25 Interface of TLC7524 to TMS320C2x 6-42
6–26 Interface Timing of TLC7524 to TMS320C2x 6-43
6–27 Interface of TLC0820 to TMS320C2x 6-44
6–28 Interface Timing of TLC0820 to TMS320C2x 6-45
6–29 I/O Port Addressing 6-46
6–30 I/O Port Processor-to-Processor Communication 6-47
6–31 Echo Canceler 6-48
6–32 High-Speed Modem 6-49
6–33 Voice Coding System 6-49
6–34 Graphics System 6-50
6–35 Robot Axis Controller Subsystem 6-51
6–36 Instrumentation System 6-51
F–1 EPROM Programming Adapter Socket F-2
F–2 V_{CC} and V_{PP} Jumper Settings for External Power F-3
F–3 EPROM Programming Data Format F-4
F–4 TMS320E25 EPROM Conversion to TMS27C64 EPROM Pinout F-5
F–5 FAST Programming Flowchart F-9
F–6 SNAP! Pulse Programming Flowchart F-10
F–7 Programming Timing F-11
F–8 EPROM Protection Flowchart F-13
F–9 How the RBIT Fits Into the TMS320E25 Block Diagrams F-14
F–10 EPROM Protection Timing F-15
G–1 System Block Diagram G-2
G–2 Multimedia Speech Encoding and Modem Communication G-3
G–3 TMS320C25 to TLC32047 Interface G-3
G–4 Typical DSP/Combo Interface G-6
G–5 DSP/Combo Interface Timing G-7
G–6 General Telecom Applications G-9
G–7 Generic Telecom Application G-9
G–8 Generic Servo Control Loop G-12
G–9 Disk Drive Control System Block Diagram G-13
G–10 TMS320C14 – TLC32071 Interface G-14
G–11 High-Speed V.32 Bis and Multistandard Modem With the TLC320AC01 AIC G-16
G–12 Applications Performance Requirements G-18
G–13 Video Signal Processing Basic System G-19
G–14 Typical Digital Audio Implementation G-19
H–1 Crystal Connection H-4
I–1 TMS320 ROM Code Flowchart I-2
K–1 TMS320 Device Nomenclature K-3
K–2 TMS320 Development Tool Nomenclature K-4

Tables

1–1 TMS320C2x Processors Overview 1-4
1–2 Typical Applications of the TMS320 Family 1-8
2–1 TMS320C2x Signal Descriptions 2-4
3–1 TMS320C2x Internal Hardware 3-9
3–2 TMS320C25/26 Memory Blocks 3-17
3–3 Memory-Mapped Registers 3-22
3–4 PM Shift Modes 3-33
3–5 Instruction Pipeline Sequence 3-40
3–6 Status Register Field Definitions 3-50
3–7 Interrupt Locations and Priorities 3-59
3–8 Serial Port Bits, Pins, and Registers 3-63
3–9 Global Data Memory Configurations 3-77
4–1 Indirect Addressing Arithmetic Operations 4-6
4–2 Bit Fields for Indirect Addressing 4-7
4–3 Instruction Symbols 4-12
4–4 Instruction Set Summary 4-14
5–1 Program Space and Time Requirements for μ-/A-Law Companding 5-69
5–2 256-Tap Adaptive Filtering Memory Space and Time Requirements 5-74
5–3 Bit-Reversal Algorithm for an 8-Point Radix-2 DIT FFT 5-77
5–4 FFT Memory Space and Time Requirements 5-81
6–1 Timing Parameters of TBP38L165-35 Direct Interface to TMS320C25 6-15
6–2 Timing Parameters of TBP38L165-35 to TMS320C25 (Address Decoding) 6-19
6–3 Wait States Required for Memory/Peripheral Access 6-20
6–4 Timing Parameters of WS57C64F-12 Interface to TMS320C25 6-24
6–5 Timing Parameters of TMS27C64-20 Interface to TMS320C25 6-26
6–6 Timing Parameters of CY7C169-25 Interface to TMS320C25 6-27
E–1 TMS320C2x Instructions by Cycle Class E-2
E–2 Cycle Timings for Cycle Classes When Not in Repeat Mode E-3
E–3 Cycle Timings for Cycle Classes When in Repeat Mode E-5
F–1 Pin Nomenclature (TMS320E25) F-5
F–2 TMS320E25 Programming Mode Levels F-6
F–3 TMS320E25 EPROM Protect and Protect Verify Mode Levels F-12
G–1 Data Converter ICs G-4
G–2 Switched-Capacitor Filter ICs G-4
G–3 Telecom Devices G-8
G–4 Switched-Capacitor Filter ICs G-8

G–5 Voice Synthesizers G-10
G–6 Speech Memories G-10
G–7 Switched-Capacitor Filter ICs G-11
G–8 Control-Related Devices G-13
G–9 Modem AFE Data Converters G-15
G–10 Audio/Video Analog/Digital Interface Devices G-20
H–1 Commonly Used Crystal Frequencies H-4
J–1 Microprocessor and Microcontroller Tests J-5
J–2 TMS320C2x Transistors J-5

Examples

5–1 Processor Initialization (TMS320C25) 5-3
5–2 Processor Initialization (TMS320C26) 5-4
5–3 BIO–XF Transfer Protocol 5-7
5–4 RS232 Transfer Protocol 5-12
5–5 TMS320C26BFNL Bootloader 5-17
5–6 Subroutines 5-22
5–7 Software Stack Expansion 5-24
5–8 Clock Divider Using Timer (TMS320C25) 5-26
5–9 Instruction Repeating 5-27
5–10 Computed GOTO 5-28
5–11 Context Save (TMS320C25) 5-30
5–12 Context Restore (TMS320C25) 5-31
5–13 Interrupt Service Routine 5-32
5–14 Moving External Data to Internal Data Memory With BLKD 5-33
5–15 Moving Program Memory to Data Memory With BLKP 5-33
5–16 Moving Program Memory to Data Memory With TBLR 5-34
5–17 Moving Internal Data Memory to Program Memory With TBLW 5-34
5–18 Moving Data From I/O Space Into Data Memory With IN 5-34
5–19 Moving Data From Data Memory to I/O Space With OUT 5-35
5–20 Configuring and Using On-Chip RAM 5-37
5–21 Program Execution From On-Chip Memory 5-39
5–22 Program Execution From On-Chip Memory (TMS320C26) 5-41
5–23 Using BIT and BBZ 5-45
5–24 Using BITT and BBNZ 5-45
5–25 Bit-Reversed Carry Addition 5-48
5–26 FFT Bit Reversals 5-48
5–27 Using the AR0 Test Bit to Calculate the Square Root of a Long Integer 5-50
5–28 Using MACD for Moving Data 5-52
5–29 Multiply 5-53
5–30 Multiply-Accumulate Using the MAC Instruction (TMS320C25) 5-54
5–31 Multiply-Accumulate Using the LTA-MPY Instruction Pair 5-54
5–32 Using SQRA 5-57
5–33 Divide 33 by 5 5-58
5–34 Using SUBC for Integer Division 5-59
5–35 Using SUBC for Fractional Division 5-59
5–36 Using NORM for Floating-Point Multiply 5-61

5–37 Using LACT for Denormalization 5-61
5–38 Row Times Column 5-62
5–39 64-Bit Addition 5-64
5–40 64-Bit Subtraction 5-65
5–41 32 × 32-Bit Multiplication 5-66
5–42 Implementing an IIR Filter 5-70
5–43 256-Tap Adaptive FIR Filter 5-73
5–44 Adaptive Filter Routine Concluded 5-74
5–45 FFT Macros 5-79
5–46 An 8-Point DIT FFT 5-81
5–47 PID Control 5-83

Chapter 1

Introduction

The TMS320 family of 16/32-bit single-chip digital signal processors combines the flexibility of a high-speed controller with the numerical capability of an array processor, offering an inexpensive alternative to custom VLSI and multichip bit-slice processors for signal processing.

The TMS32010, the first digital signal processor in the TMS320 family, was introduced in 1982. Since that time, the TMS320 family has established itself as the industry standard for digital signal processing. The powerful instruction set, inherent flexibility, high-speed number-crunching capabilities, and innovative architecture make these high-performance, cost-effective processors ideal for many telecommunications, computer, commercial, industrial, and military applications.

Note:

Throughout this document, TMS320C2x refers to the TMS320C25, TMS320C25-33, TMS320C25-50, TMS320E25, TMS320C26, and TMS320C28 unless stated otherwise. Where applicable, ROM includes the on-chip EPROM of the TMS320E25.

Topics in this chapter include

Topic **Page**

1.1 General Description 1-2

1.2 Key Features 1-6

1.3 Typical Applications 1-8

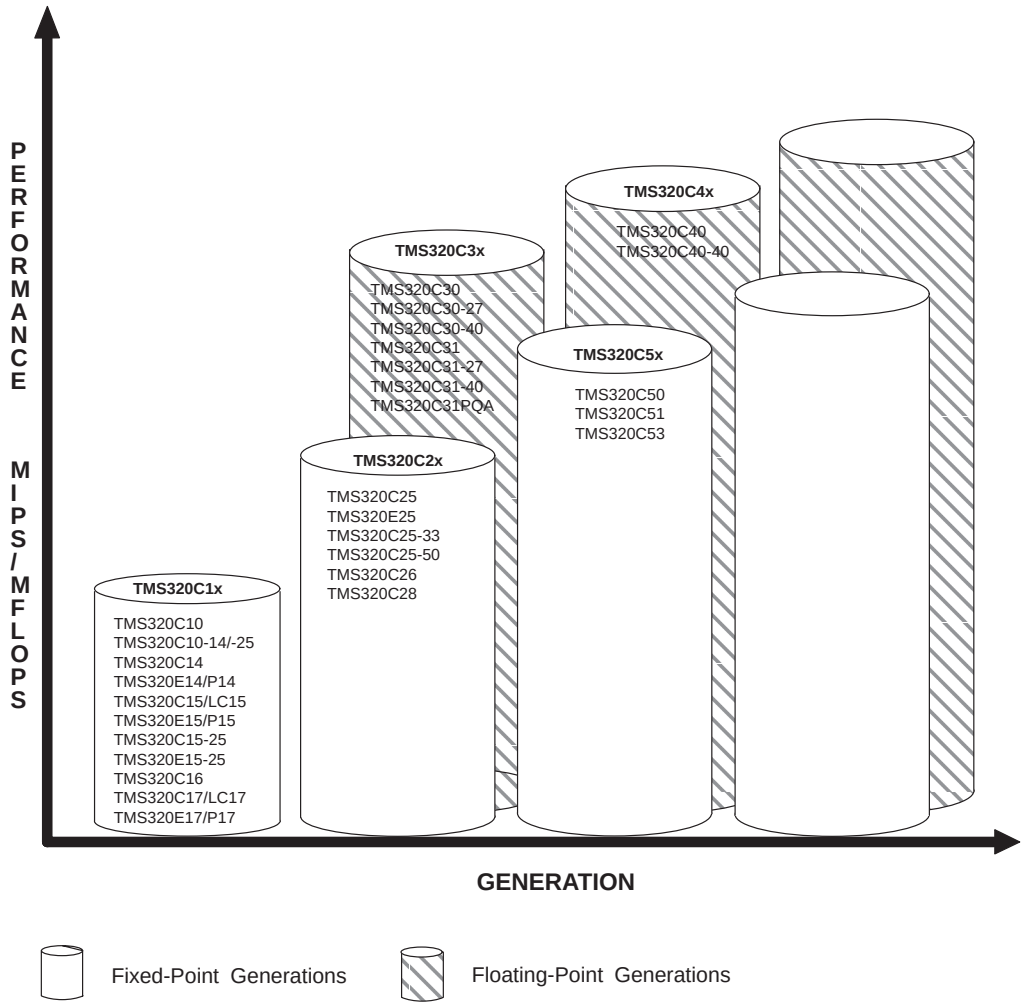
1.1 General Description

The TMS320 family currently consists of five generations: TMS320C1x, TMS320C2x, TMS320C3x, TMS320C4x, and TMS320C5x (see Figure 1–1). The family expansion includes enhancements of existing generations and more powerful new generations of digital signal processors. Many features are common among these generations. Some specific features are added in each processor to provide different cost/performance tradeoffs. Software compatibility is maintained throughout the family to protect the user's investment in architecture. Each processor has software and hardware tools to facilitate rapid design.

This document discusses the TMS320C2x devices:

- TMS320C25, a CMOS 40-MHz digital signal processor capable of twice the performance of the TMS320C1x devices
- TMS320C25-33 a CMOS 33-MHz version of the TMS32025
- TMS320C25-50, a CMOS enhanced-speed (50-MHz) version of the TMS320C25
- TMS320E25, a version of the TMS320C25 (40-MHz) with on-chip ROM replaced by secure, on-chip EPROM
- TMS320C26, a version of the TMS320C25 (40-MHz) with expanded configurable program/data RAM
- The TMS320C28, a version of the TMS320C25 (40-MHz) with expanded 8K-word on-chip ROM and an added power-down mode.

Figure 1–1. TMS320 Device Evolution



Plans for expansion of the TMS320 family include more spinoffs of the existing generations as well as more powerful future generations of digital signal processors.

The TMS320 family combines the high performance and specialized features necessary in digital signal processing (DSP) applications with an extensive program of development support, including hardware and software development tools, product documentation, textbooks, newsletters, DSP design workshops, and a variety of application reports. See Appendix K for a discussion of the wide range of development tools available.

The combination of the TMS320's Harvard-type architecture (separate program and data buses) and its special digital signal processing instruction set provide speed and flexibility to execute 12.8 MIPS (million instructions per second). The TMS320 family optimizes speed by implementing functions in hardware that other processors implement through software or microcode. This hardware-intensive approach provides the design engineer with power previously unavailable on a single chip.

The TMS320C2x generation includes six members: TMS320C25, TMS320C25-33, TMS320C25-50, TMS320E25, TMS320C26, and TMS320C28. Table 1–1 provides an overview of the TMS320C2x generation of processors with comparisons of memory, I/O, cycle timing, and package type.

Table 1–1. TMS320C2x Processors Overview

Device	On-chip RAM	Memory ROM/ EPROM	Off-chip Prog Data		I/O Ports †			Cycle Time (ns)	Package Type*			
					Ser	Par	DMA		PGA	PLCC	CER	QFP
TMS320C25‡	544	4K	64K	64K	Yes	16 × 16	Con	100	68	68	—	—
TMS320C25-33	544	4K	64K	64K	Yes	16 × 16	Con	120	—	68	—	—
TMS320C25-50§	544	4K	64K	64K	Yes	16 × 16	Con	80	—	68	—	—
TMS320E25§	544	4K	64K	64K	Yes	16 × 16	Con	100	—	—	68	80
TMS320C26	1568	256	64K	64K	Yes	16 × 16	Con	100	—	68	—	—
TMS320C28	544	8K	64K	64K	Yes	16 × 16	Con	100	—	68	—	80

†Ser = serial; Par = parallel; DMA = direct memory access; Con = concurrent DMA.
‡Military version available; contact nearest TI Field Sales Office for availability.
§Military version planned; contact nearest TI Field Sales Office for details.
*PGA = 68-pin grid array; PLCC = plastic-leaded chip carrier; CER = surface mount ceramic-leaded chip carrier (CER-QUAD); QFP = plastic quad flat package

The **TMS320C25**, like all members of the TMS320C2x generation, is processed in CMOS technology. The TMS320C25 is capable of executing 10 million instructions per second. Enhanced features such as 24 additional instructions (133 total), eight auxiliary registers, an eight-level hardware stack, 4K words of on-chip program ROM, a bit-reversed indexed addressing mode, and the low power dissipation inherent to the CMOS process contribute to the high performance.

The **TMS320C25-33** is a 33-MHz version of the TMS320C25. It is capable of an instruction cycle of 120 ns. It is architecturally identical to the 40-MHz version of the TMS320C25 and is pin-for-pin and object-code compatible with the TMS320C25.

The **TMS320C25-50** is a high-speed version of the TMS320C25. It is capable of an instruction cycle time of 80 ns. It is architecturally identical to the 40-MHz version of the TMS320C25 and is pin-for-pin and object-code compatible with the TMS320C25.

The **TMS320E25** is identical to the TMS320C25, except that the on-chip 4K-word program ROM is replaced with a 4K-word on-chip program EPROM. On-chip EPROM allows realtime code development and modification for immediate evaluation of system performance.

The **TMS320C26** is pin-for-pin and object-code compatible (except for RAM configuration instructions) with the TMS320C25. It is capable of an instruction cycle time of 100 ns. The enhancement over the TMS320C25 consists of a larger, configurable, on-chip RAM divided into 4 blocks, for a total 1568-word program/data space. The TMS320C26 is similar to the TMS320C25 except for its internal memory configuration. This is discussed in Section 3.4 and in Appendix B.

The **TMS320C28** is object code-compatible with the TMS320C25. It is capable of an instruction cycle time of 100 ns. The TMS320C28 contains an expanded 8K words of on-chip program ROM and an added power-down mode, which conserves power while saving the contents of on-chip SRAM (B0, B1, and B2).

1.2 Key Features

Key features of the TMS320C2x devices are listed below. Those that pertain to a particular device are followed by the device name within parentheses.

- Instruction cycle timing:

  80-ns (TMS320C25-50)
  100-ns (TMS320C25, TMS320E25, TMS320C26, and TMS320C28)
  120-ns (TMS320C25-33)

- 544-word programmable on-chip data RAM
- 1568-word configurable program/data RAM (TMS320C26 only)
- 4K-word on-chip program ROM (TMS320C25, TMS302C25-33, and TMS320C25-50)
- 8K-word on-chip program ROM (TMS320C28 only)
- Secure 4K-word on-chip program EPROM (TMS320E25)
- 128K-word total data/program memory space
- 32-bit ALU/accumulator
- 16- $\times$16-bit parallel multiplier with a 32-bit product
- Single-cycle multiply/accumulate instructions
- Repeat instructions for efficient use of program space and enhanced execution
- Block moves for data/program management
- On-chip timer for control operations
- Up to eight auxiliary registers with dedicated arithmetic unit
- Up to eight-level hardware stack
- Sixteen input and sixteen output channels
- 16-bit parallel shifter
- Wait states for communication to slower off-chip memories/peripherals
- Serial port for direct codec interface
- Synchronization input for synchronous multiprocessor configurations

- ❑ Global data memory interface
- ❑ TMS320C1x source-code upward compatibility
- ❑ Concurrent DMA using an extended hold operation
- ❑ Instructions for adaptive filtering, FFT, and extended-precision arithmetic
- ❑ Bit-reversed indexed-addressing mode for radix-2 FFT
- ❑ On-chip clock generator
- ❑ Single 5-V supply
- ❑ Power-down mode (TMS320C28 only)
- ❑ Device packaging:

  68-pin PGA (TMS320C25)
  68-lead PLCC (TMS320C25, TMS320C26, and TMS320C28)
  68-lead CER-QUAD (TMS320E25)
  80-pin QFP (TMS320C28)

- ❑ Commercial and military versions available

1.3 Typical Applications

The TMS320 family's unique versatility and realtime performance offer flexible design approaches in a variety of applications. In addition, TMS320 devices can simultaneously provide the multiple functions often required in those complex applications. Table 1–2 lists typical TMS320 family applications.

Table 1–2. Typical Applications of the TMS320 Family

General-Purpose DSP	Graphics/Imaging	Instrumentation
Digital Filtering Convolution Correlation Hilbert Transforms Fast Fourier Transforms Adaptive Filtering Windowing Waveform Generation	3-D Rotation Robot Vision Image Transmission/ Compression Pattern Recognition Image Enhancement Homomorphic Processing Workstations Animation/Digital Map	Spectrum Analysis Function Generation Pattern Matching Seismic Processing Transient Analysis Digital Filtering Phase-Locked Loops
Voice/Speech	**Control**	**Military**
Voice Mail Speech Vocoding Speech Recognition Speaker Verification Speech Enhancement Speech Synthesis Text-to-Speech	Disk Control Servo Control Robot Control Laser Printer Control Engine Control Motor Control	Secure Communications Radar Processing Sonar Processing Image Processing Navigation Missile Guidance Radio Frequency Modems
Telecommunications		**Automotive**
Echo Cancellation ADPCM Transcoders Digital PBXs Line Repeaters Channel Multiplexing 1200 to 19200-bps Modems Adaptive Equalizers DTMF Encoding/Decoding Data Encryption	FAX Cellular Telephones Speaker Phones Digital Speech Interpolation (DSI) X.25 Packet Switching Video Conferencing Spread Spectrum Communications	Engine Control Vibration Analysis Antiskid Brakes Adaptive Ride Control Global Positioning Navigation Voice Commands Digital Radio Cellular Telephones
Consumer	**Industrial**	**Medical**
Radar Detectors Power Tools Digital Audio/TV Music Synthesizer Toys and Games Solid-State Answering Machines	Robotics Numeric Control Security Access Power Line Monitors	Hearing Aids Patient Monitoring Ultrasound Equipment Diagnostic Tools Prosthetics Fetal Monitors

Many of the TMS320C2x features, such as single-cycle multiply/accumulate instructions, 32-bit arithmetic unit, large auxiliary register file with a separate arithmetic unit, and large on-chip RAM and ROM make the device particularly applicable in digital signal processing systems. At the same time, general-purpose applications are greatly enhanced by the large address spaces, on-chip timer, serial port, multiple interrupt structure, provision for external wait states, and capability for multiprocessor interface and direct memory access.

The TMS320C2x has the flexibility to be configured to satisfy a wide range of system requirements. This allows the device to be applied in systems currently using costly bit-slice processors or custom ICs. These are examples of such system configurations:

- A standalone system using on-chip memory,
- Parallel multiprocessing systems with shared global data memory, or
- Host/peripheral coprocessing using interface control signals.

Chapter 2

Pinouts and Signal Descriptions

The TMS320C2x generation digital signal processors are available in one or more of four package types. The TMS320C25 (40-MHz version only) is available in a 68-pin grid array (PGA) package. The TMS320C25 (33-MHz, 40-MHz, and 50-MHz versions) and the TMS320C26 are available in a plastic 68-lead chip carrier (PLCC) package. The TMS320E25 is packaged in a ceramic surface mount 68-lead chip carrier (CER-QUAD) package. The TMS320C28 is available in a 80-pin quad flat package (QFP). All TMS320 packages conform to JEDEC specifications.

Conversion sockets that accept PLCC and CER-QUAD packages and have a PGA footprint are commercially available. For more information, refer to Appendix D.

When using the XDS emulator, refer to subsection 6.1.3 for user target design considerations.

The TMS320C26 is similar to the TMS320C25 except for its internal memory configuration. This is discussed in Section 3.4 and in Appendix B.

Topics in this chapter include

Topic **Page**

2.1 TMS320C2x Pinouts 2-2

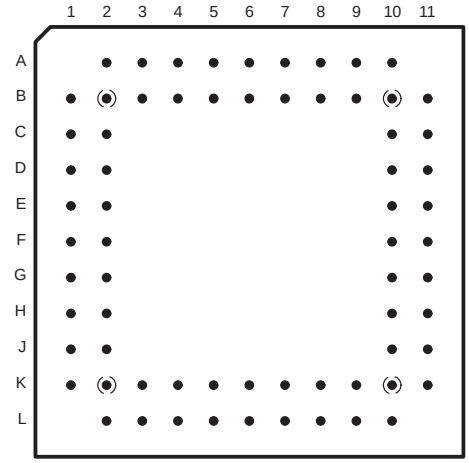
2.2 TMS320C2x Signal Descriptions 2-4

2.1 TMS320C2x Pinouts

Figure 2–1 shows pinouts of the PGA, PLCC, and CER-QUAD packages for the TMS320C2x devices. Note that the pinout and external dimensions of PLCC and CER-QUAD are identical. Figure 2–2 shows preliminary pinouts of the QFP package for the TMS320C28 device.

Figure 2–1. TMS320C2x Pin Assignments

68-Pin GB Pin Grid Array
Ceramic Package (Top View)



68-Pin FN Plastic Leaded Chip Carrier Package and 68-Pin FZ CER-QUAD Package (Top View)

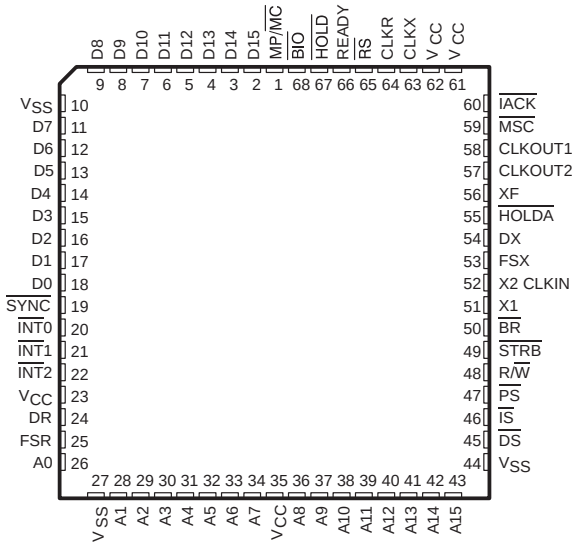
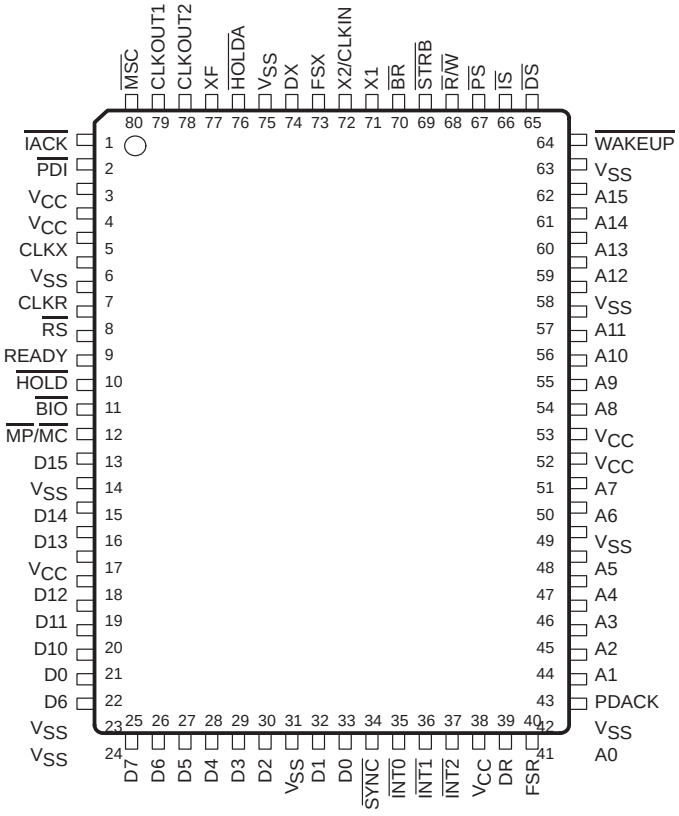


Figure 2–2. TMS320C28 Pin Assignments

80-Pin PH Quad Flat Package †
(Top View)



† Packages are shown for pinout reference only.

ADVANCE INFORMATION

2.2 TMS320C2x Signal Descriptions

The signal descriptions for the TMS320C2x devices are provided in this section. Table 2–1 lists each signal, its pin location (PGA, PLCC, and CER-QUAD), function, and operating mode(s): that is, input, output, or high-impedance state as indicated by I, O, or Z. The signals in Table 2–1 are grouped according to function and alphabetized within that grouping.

Table 2–1. TMS320C2x Signal Descriptions

Signal	Pin (PGA/PLCC†)	I/O/Z‡	Description
		Address/Data Buses	
A15 MSB A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 A0 LSB	L10/43 K9/42 L9/41 K8/40 L8/39 K7/38 L7/37 K6/36 K5/34 L5/33 K4/32 L4/31 K3/30 L3/29 K2/28 K1/26	O/Z	Parallel address bus A15 (MSB) through A0 (LSB). Multiplexed to address external data/program memory or I/O. Placed in high-impedance state in the hold mode.
D15 MSB D14 D13 D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0 LSB	B6/2 A5/3 B5/4 A4/5 B4/6 A3/7 B3/8 A2/9 B2/11 C1/12 C2/13 D1/14 D2/15 E1/16 E2/17 F1/ 18	I/O/Z	Parallel data bus D15 (MSB) through D0 (LSB). Multiplexed to transfer data between the TMS320C2x and external data/program memory or I/O devices. Placed in the high-impedance state when not outputting or when $\overline{RS}$ or $\overline{HOLD}$ is asserted.
		Interface Control Signals	
$\overline{DS}$ $\overline{PS}$ $\overline{IS}$	K10/45 J10/47 J11/46	O/Z	Data, program, and I/O space select signals. Always high unless low level asserted for communicating to a particular external space. Placed in high-impedance state in the hold mode.
READY	B8/66	I	Data ready input. Indicates that an external device is prepared for the bus transaction to be completed. If the device is not ready (READY = 0), the TMS320C2x waits one cycle and checks READY again. READY also indicates a bus grant to an external device after a $\overline{BR}$ (bus request) signal.

† Pin numbers apply to CER-QUAD as well as to PLCC.
‡ Input/Output/High-impedance state.

Table 2–1. TMS320C2x Signal Descriptions (Continued)

Signal	Pin (PGA/PLCC†)	I/O/Z‡	Description
Interface Control Signals (Continued)			
R/$\overline{W}$	H11/48	O/Z	Read/write signal. Indicates transfer direction when communicating to an external device. Normally in read mode (high), unless low level asserted for performing a write operation. Placed in high-impedance state in the hold mode.
$\overline{STRB}$	H10/49	O/Z	Strobe signal. Always high unless asserted low to indicate an external bus cycle. Placed in high-impedance state in the hold mode.
Multiprocessing Signals			
$\overline{BR}$	G11/50	O	Bus request signal. Asserted when the TMS320C2x requires access to an external global data memory space. READY is asserted to the device when the bus is available and the global data memory is available for the bus transaction.
$\overline{HOLD}$	A7/67	I	Hold input. When this signal is asserted, the TMS320C2x places the data, address, and control lines in the high-impedance state.
$\overline{HOLDA}$	E10/55	O	Hold acknowledge signal. Indicates that the TMS320C2x has gone into the hold mode and that an external processor may access the local external memory of the TMS320C2x.
$\overline{SYNC}$	F2/19	I	Synchronization input. Allows clock synchronization of two or more TMS320C2xs. $\overline{SYNC}$ is an active-low signal and must be asserted on the rising edge of CLKIN.
Interrupt and Miscellaneous Signals			
$\overline{BIO}$	B7/68	I	Branch control input. Polled by BIOZ instruction. If $\overline{BIO}$ is low, the TMS320C2x executes a branch. This signal must be active during the BIOZ instruction fetch.
$\overline{IACK}$	B11/60	O	Interrupt acknowledge signal. Output is valid only while CLKOUT1 is low. Indicates receipt of an interrupt and that the program is branching to the interrupt-vector location designated by A15–A0.
$\overline{INT}$2 $\overline{INT}$1 $\overline{INT}$0	H1/22 G2/21 G1/20	I	External user interrupt inputs. Prioritized and maskable by the interrupt mask register and the interrupt mode bit.
MP/$\overline{MC}$	A6/1	I	Microprocessor/microcomputer mode select pin for the TMS320C25. When asserted low (microcomputer mode), the pin causes the internal ROM to be mapped into the lower 4K words of the program memory map. In the microprocessor mode, the lower 4K words of program memory are external.

† Pin numbers apply to CER-QUAD as well as to PLCC.
‡ Input/Output/High-impedance state.

Table 2–1. TMS320C2x Signal Descriptions (Continued)

Signal	Pin (PGA/PLCC†)	I/O/Z‡	Description
Interrupt and Miscellaneous Signals (Continued)			
$\overline{MSC}$	C10/59	O	Microstate complete signal. Asserted low and valid only during CLKOUT1 low when the TMS320C2x has just completed a memory operation, such as an instruction fetch or a data memory read/write. $\overline{MSC}$ can be used to generate a one wait-state READY signal for slow memory.
$\overline{RS}$	A8/65	I	Reset input. Causes the TMS320C2x to terminate execution and forces the program counter to zero. When $\overline{RS}$ is brought to a high level, execution begins at location zero of program memory. $\overline{RS}$ affects various registers and status bits.
XF	D11/56	O	External flag output (latched software-programmable signal). Used for signaling other processors in multiprocessor configurations or as a general-purpose output pin.
Supply/Oscillator Signals			
CLKOUT1	C11/58	O	Master clock output signal (CLKIN frequency/4). CLKOUT1 rises at the beginning of quarter-phase 3 (Q3) and falls at the beginning of quarter-phase 1 (Q1).
CLKOUT2	D10/57	O	A second clock output signal. CLKOUT2 rises at the beginning of quarter-phase 2 (Q2) and falls at the beginning of quarter-phase 4 (Q4).
V_{CC}	A10/61 B10/62 H2/23 L6/35	I	Four 5-V supply pins, tied together externally.
V_{SS}	B1/10 K11/44 L2/27	I	Three ground pins, tied together externally.
X1	G10/51	O	Output pin from the internal oscillator for the crystal. If a crystal is not used, this pin should be left unconnected.
X2/CLKIN	F11/52	I	Input pin to the internal oscillator from the crystal. If crystal is not used, a clock may be input to the device on this pin

† Pin numbers apply to CER-QUAD as well as to PLCC.
‡ Input/Output/High-impedance state.

Table 2–1. TMS320C2x Signal Descriptions (Continued)

Signal	Pin (PGA/PLCC†)	I/O/Z‡	Description
Serial Port Signals			
CLKR	B9/64	I	Receive clock input. External clock signal for clocking data from the DR (data receive) pin into the RSR (serial port receive shift register). Must be present during serial port transfers.
CLKX	A9/63	I	Transmit clock input. External clock signal for clocking data from the XSR (serial port transmit shift register) to the DX (data transmit) pin. Must be present during serial port transfers.
DR	J1/24	I	Serial data receive input. Serial data is received in the RSR (serial port receive shift register) via the DR pin.
DX	E11/54	O/Z	Serial data transmit output. Serial data transmitted from the XSR (serial port transmit shift register) via the DX pin. Placed in high-impedance state when not transmitting.
FSR	J2/25	I	Frame synchronization pulse for receive input. The falling edge of the FSR pulse initiates the data-receive process, beginning the clocking of the RSR.
FSX	F10/53	I/O	Frame synchronization pulse for transmit input/output. The falling edge of the FSX pulse initiates the data- transmit process, beginning the clocking of the XSR. Following reset, the default operating condition of FSX is as an input. This pin may be selected by software to be an output when the TXM bit in the status register is set to 1.

† Pin numbers apply to CER-QUAD as well as to PLCC.
‡ Input/Output/High-impedance state.

Note: See Appendix C for TMS320C28 signal descriptions.

Chapter 3

Architecture

The architectural design of the TMS320C2x emphasizes overall system speed, communication, and flexibility in processor configuration. Control signals and instructions provide block memory transfers, communication to slower off-chip devices, and multiprocessing implementations. Single-cycle multiply/accumulate instructions, two large on-chip RAM Blocks, eight auxiliary registers with a dedicated arithmetic unit, a serial port, a hardware timer, and a faster I/O for data-intensive signal processing are features that increase throughput for DSP applications.

The TMS320C26 is similar to the TMS320C25 except for its internal memory configuration. This is discussed in Section 3.4 and in Appendix B.

Topics in this chapter include:

Topic **Page**

3.1	Architectural Overview	3-2
3.2	Functional Block Diagram	3-6
3.3	Internal Hardware Summary	3-9
3.4	Memory Organization	3-12
3.5	Central Arithmetic Logic Unit (CALU)	3-28
3.6	System Control	3-35
3.7	External Memory and I/O Interface	3-55
3.8	Interrupts	3-60
3.9	Serial Port	3-64
3.10	Multiprocessing and Direct Memory Access (DMA)	3-76
3.11	General Description of the TMS320C26	3-83
3.12	General Description of the TMS320C28	3-84

3.1 Architectural Overview

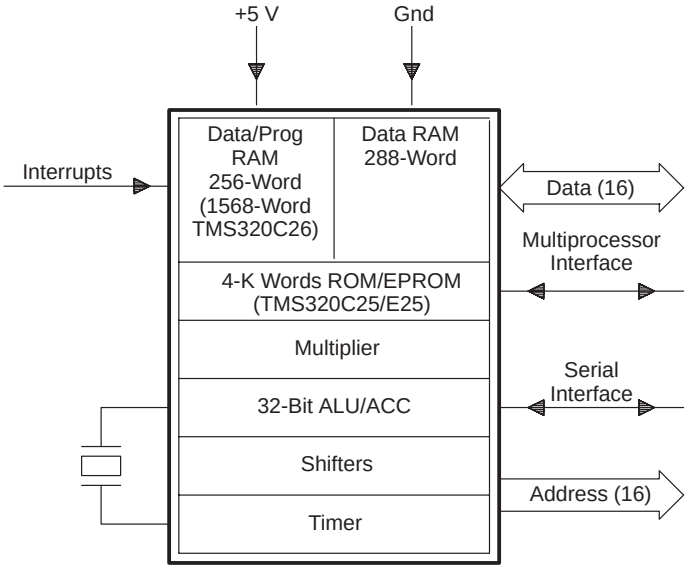
Harvard Architecture. The TMS320C2x high-performance digital signal processors, like the TMS320C1x devices, implement a Harvard-type architecture that maximizes processing power by maintaining two separate memory bus structures, program and data, for full-speed execution. Instructions are included to provide data transfers between the two spaces. Externally, the program and data memory can be multiplexed over the same bus so as to maximize the address range for both spaces while minimizing the pin count of the device.

On-Chip Memory. The TMS320C25 provides increased flexibility in system design by two large on-chip data RAM blocks (a total of 544 16-bit words), one of which is configurable either as program or data memory (see Figure 3–1). The TMS320C26 provides three large on-chip RAM blocks, configurable either as separate program and data spaces or as three continuous data blocks, to provide increased flexibility in system design. An off-chip 64K-word directly addressable data memory address space is included to facilitate implementations of DSP algorithms.

The large on-chip 4K-word masked ROM on the TMS320C25 can reduce the cost of systems, thus providing for a true single-chip DSP solution (see Figure 3–1). Programs of up to 4K words can be masked into the internal program ROM. The remainder of the 64K-word program memory space is located externally. Large programs can execute at full speed from this memory space. Programs may also be downloaded from slow external memory to on-chip RAM for full-speed operation.

The 4K-word on-chip EPROM on the TMS320E25 allows realtime code development and modification for immediate evaluation of system performance. Instructions can be executed from the EPROM at full speed. The EPROM is equipped with a security mechanism allowing you to protect proprietary information. A programming adapter socket is available from Texas Instruments that provides 68- to 28-pin conversion for programming with standard PROM programmers. Refer to Appendix F for details.

Figure 3–1. TMS320C2x Simplified Block Diagram



Arithmetic Logic Unit. The TMS320C2x performs 2s-complement arithmetic using the 32-bit ALU and accumulator. The ALU is a general-purpose arithmetic unit that operates using 16-bit words taken from data RAM or derived from immediate instructions or using the 32-bit result of the multiplier's product register. In addition to the usual arithmetic instructions, the ALU can perform Boolean operations, providing the bit manipulation ability required of a high-speed controller. The accumulator stores the output from the ALU and is the second input to the ALU. The accumulator is 32 bits in length and is divided into a high-order word (bits 31 through 16) and a low-order word (bits 15 through 0). Instructions are provided for storing the high- and low-order accumulator words in memory.

Multiplier. The multiplier performs a 16 × 16-bit 2s-complement multiplication with a 32-bit result in a single instruction cycle. The multiplier consists of three elements: the T register, P register, and multiplier array. The 16-bit T register temporarily stores the multiplicand; the P register stores the 32-bit product. Multiplier values come from data memory, from program memory when using the MAC/MACD instructions, or immediately from the MPYK (multiply immediate) instruction word. The fast on-chip multiplier allows the device to perform efficiently the fundamental DSP operations such as convolution, correlation, and filtering.

The TMS320C2x scaling shifter has a 16-bit input connected to the data bus and a 32-bit output connected to the ALU. The scaling shifter produces a left-shift of 0 to 16 bits on the input data, as programmed in the instruction. The LSBs of the output are filled with zeros, and the MSBs may be either filled with zeros or sign-extended, depending upon the state of the sign-extension mode bit of status register ST1. Additional shift capabilities enable the processor to perform numerical scaling, bit extraction, extended arithmetic, and overflow prevention.

Memory Interface. The TMS320C2x local memory interface consists of a 16-bit parallel data bus (D15–D0), a 16-bit address bus (A15–A0), three pins for data/program memory or I/O space select ($\overline{DS}$, $\overline{PS}$, and $\overline{IS}$), and various system control signals. The R/$\overline{W}$ signal controls the direction of a data transfer, and the $\overline{STRB}$ signal provides a timing signal to control the transfer. When using on-chip program RAM, ROM/EPROM, or high-speed external program memory, the TMS320C2x runs at full speed without wait states. The use of a READY signal allows wait-state generation for communicating with slower off-chip memories.

Up to eight levels of hardware stack are provided for saving the contents of the program counter during interrupts and subroutine calls. Instructions are available for saving the device's complete context. PUSH and POP instructions permit a level of nesting restricted only by the amount of available RAM. The interrupts used in these devices are maskable.

All control operations are supported on the TMS320C2x by an on-chip memory-mapped 16-bit timer, a repeat counter, three external maskable user interrupts, and internal interrupts generated by serial port operations or by the timer. A built-in mechanism protects from instructions that are repeated or become multicycle due to the READY signal and from holds and interrupts.

Serial Port. An on-chip full-duplex serial port provides direct communication with serial devices such as codecs, serial A/D converters, and other serial systems. The interface signals are compatible with codecs and many other serial devices with a minimum of external hardware. The two serial port memory-mapped registers (the data transmit/receive registers) may be operated in either an 8-bit byte or 16-bit word mode. Each register has an external clock input, a framing synchronization input, and associated shift registers.

Multiprocessing Applications. The TMS320C2x has the capability of allocating global data memory space and communicating with that space via the $\overline{BR}$ (bus request) and READY control signals. The 8-bit memory-mapped global memory allocation register (GREG) specifies up to 32K words of the TMS320C2x data memory as global external memory. The contents of the register determine the size of the global memory space. If the current instruction addresses an operand within that space, $\overline{BR}$ is asserted to request control of the bus. The length of the memory cycle is controlled by the READY line.

Direct Memory Access. The TMS320C2x supports direct memory access (DMA) to its external program/data memory using the $\overline{\text{HOLD}}$ and $\overline{\text{HOLDA}}$ signals. Another processor can take complete control of the TMS320C2x external memory by asserting $\overline{\text{HOLD}}$ low. This causes the TMS320C2x to place its address, data, and control lines in the high-impedance state. Signaling between the external processor and the TMS320C2x can be performed by using interrupts. On the TMS320C2x, two modes are available: a mode in which execution is suspended during assertion of $\overline{\text{HOLD}}$, and a concurrent DMA mode in which the TMS320C2x continues to execute its program while operating from internal RAM or ROM, thus greatly increasing throughput in data-intensive applications.

3.2 Functional Block Diagram

The functional block diagram shown in Figure 3–2 and Figure 3–3 outlines the principal blocks and data paths within the TMS320C2x processors. Further details of the functional blocks are provided in the succeeding sections. Refer to Section 3.3, *Internal Hardware Summary*, for definitions of the symbols used in Figure 3–2. The block diagram also shows all of the TMS320C2x interface pins. Figure 3–3 shows the block diagram of the TMS320C26.

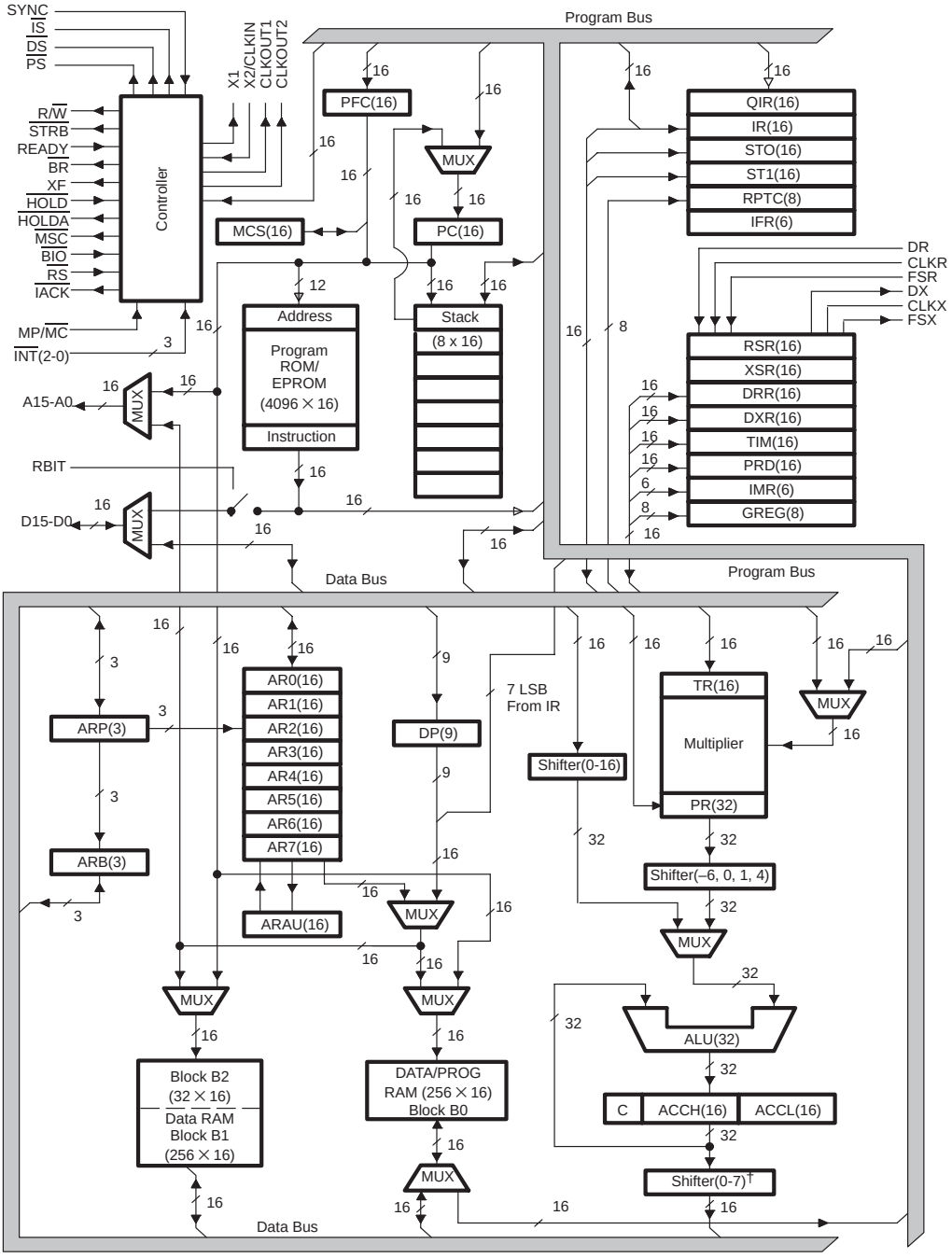
The TMS320C2x architecture is built around two major buses: the program bus and the data bus. The program bus carries the instruction code and immediate operands from program memory. The data bus interconnects various elements, such as the central arithmetic logic unit (CALU) and the auxiliary register file, to the data RAM. Together, the program and data buses can carry data from on-chip data RAM and internal or external program memory to the multiplier in a single cycle for multiply/accumulate operations.

The TMS320C2x has a high degree of parallelism; for example, while the data is being operated upon by the CALU, arithmetic operations may also be implemented in the auxiliary register arithmetic unit (ARAU). Such parallelism results in a powerful set of arithmetic, logic, and bit-manipulation operations that may all be performed in a single machine cycle.

LEGEND:

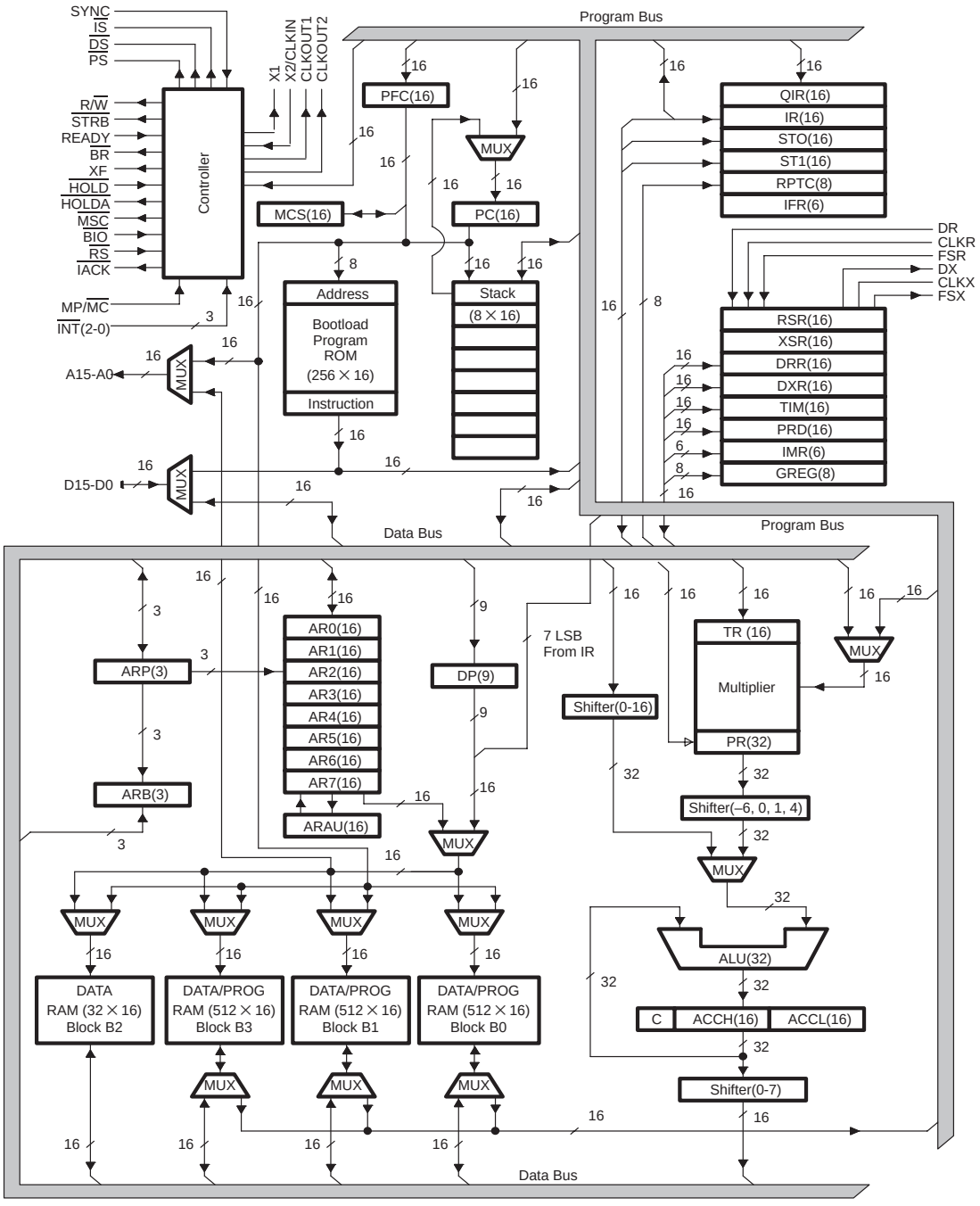
ACCH	= Accumulator high	IFR	= Interrupt flag register	PC	= Program Counter
ACCL	= Accumulator low	IMR	= Interrupt mask register	PFC	= Prefetch counter
ALU	= Arithmetic logic unit	IR	= Instruction register	RPTC	= Repeat instruction counter
ARAU	= Auxiliary register arithmetic unit	MCS	= Microcall stack	GREG	= Global memory allocation register
ARB	= Auxiliary register pointer buffer	QIR	= Queue instruction register	RSR	= Serial port receive shift register
ARP	= Auxiliary register pointer	PR	= Product register	XSR	= Serial port transmit shift register
DP	= Data memory page pointer	PRD	= Period register for timer	AR0-AR	= Auxiliary registers
DRR	= Serial port data receive register	TIM	= Timer	ST0.ST	= Status registers
DXR	= Serial port data transmit register	TR	=Temporary register	C	= Carry bit

Figure 3–2. TMS320C25/E25 Block Diagram



NOTE: Shaded areas indicate a bus.

Figure 3–3. TMS320C26 Block Diagram



NOTE: Shaded areas indicate a bus.

3.3 Internal Hardware Summary

The TMS320C2x internal hardware implements functions that other processors typically perform in software or microcode. For example, the device contains hardware for single-cycle 16 × 16-bit multiplication, data shifting, and address manipulation. This hardware-intensive approach provides computing power previously unavailable on a single chip.

Table 3–1 presents a summary of the TMS320C2x internal hardware. This summary table, which includes the internal processing elements, registers, and buses, is alphabetized within each functional grouping. All of the symbols used in this table correspond to the symbols used in the block diagram of Section 3.2, the succeeding block diagrams in this section, and the text throughout this document.

Table 3–1. TMS320C2x Internal Hardware

Unit	Symbol	Function
Accumulator	ACC (31–0) ACCH (31–16) ACCL (15–0)	A 32-bit accumulator split in two halves: ACCH (accumulator high) and ACCL (accumulator low). Used for storage of ALU output.
Arithmetic Logic Unit	ALU	A 32-bit twos-complement arithmetic logic unit having two 32-bit input ports and one 32-bit output port feeding the accumulator.
Auxiliary Register Arithmetic Unit	ARAU	A 16-bit unsigned arithmetic unit used to perform operations on auxiliary register data.
Auxiliary Register File	AR0–AR7 (15–0)	A register file containing eight 16-bit auxiliary registers (AR0–AR7), used for addressing data memory, temporary storage, or integer arithmetic processing through the ARAU.
Auxiliary Register File Bus	AFB(15–0)	A 16-bit bus that carries data from the AR pointed to by the ARP.
Auxiliary Register Pointer	ARP(2–0)	A 3-bit register used to select one of five or eight auxiliary registers.
Auxiliary Register Pointer Buffer	ARB(2–0)	A 3-bit register used to buffer the ARP. Each time the ARP is loaded, the old value is written to the ARB, except during an LST (load status register) instruction. When the ARB is loaded with an LST1, the same value is also copied into ARP.
Central Arithmetic Logic Unit	CALU	The grouping of the ALU, multiplier, accumulator, and scaling shifter.
Data Bus	D(15–0)	A 16-bit bus used to route data.
Data Memory Address Bus	DAB(15–0)	A 16-bit bus that carries the data memory address.
Data Memory Page Pointer	DP(8–0)	A 9-bit register pointing to the address of the current page. Data pages are 128 words each, resulting in 512 pages of addressable data memory space (some locations are reserved).
Direct Data Memory Address Bus	DRB(15–0)	A 16-bit bus that carries the direct address for the data memory, which is the concatenation of the DP register with the seven LSBs of the instruction.
Global Memory Allocation Register	GREG(7–0)	An 8-bit memory-mapped register for allocating the size of the global memory space.

Table 3–1. TMS320C2x Internal Hardware (Continued)

Unit	Symbol	Function
Instruction Register	IR(15–0)	A 16-bit register used to store the currently executing instruction.
Interrupt Flag Register	IFR(5–0)	A 6-bit flag register used to latch the active-low external user interrupts INT(2–0), the internal interrupts XINT/RINT (serial port transmit/receive), and TINT (timer) interrupts. The IFR is not accessible through software.
Interrupt Mask Register	IMR(5–0)	A 6-bit memory-mapped register used to mask interrupts.
Microcall Stack	MCS (15–0)	A single-word stack that temporarily stores the contents of the PFC while the PFC is being used to address data memory with the block move (BLKD/BLKP), multiply-accumulate (MAC/MACD), and table read/write (TBLR/TBLW)and table read/write (TBLR/TBLW) instruction
Multiplier	MULT	A 16 × 16-bit parallel multiplier.
Period Register	PRD (15–0)	A 16-bit memory-mapped register used to reload the timer.
Prefetch Counter	PFC (15–0)	A 16-bit counter used to prefetch program instructions. The PFC contains the address of the instruction currently being prefetched. It is updated when a new prefetch is initiated. The PFC is also used to address program memory when using the block move (BLKP), multiply-accumulate (MAC/MACD), and table read/write (TBLR/TBLW) instructions and to address data memory when using the block move (BLKD) instruction.
Product Register	PR(31–0)	A 32-bit product register used to hold the multiplier product. The PR can also be accessed as the most or least significant words by using the SPH/SPL (store P register high/low) instructions.
Program Bus	P(15–0)	A 16-bit bus used to route instructions (and data for the MAC and MACD instructions).
Program Counter	PC (15–0)	A 16-bit program counter used to address program memory. The PC always contains the address of the next instruction to be executed. The PC contents are updated following each instruction decode operation.
Program Memory Address Bus	PAB(15–0)	A 16-bit bus that carries the program memory address.
Queue Instruction Register	QIR(15–0)	A 16-bit register used to store prefetched instructions.
Random Access Memory (data or program)	RAM (B0)	A RAM block with 256 × 16 locations configured as either data or program memory. (512 × 16 for TMS320C26)
Random Access Memory (data only)	RAM (B1)	A data RAM block, organized as 256 × 16 locations. (512 × 16 can be configured as program or data for TMS320C26)
Random Access Memory (data only)	RAM (B2)	A data RAM block, organized as 32 × 16 locations.
Random Access Memory (data or program)	RAM (B3) (TMS320C26 only)	A RAM block with 512 × 16 locations configured as either data or program memory (TMS320C26 only).
Read Only Memory	ROM	A ROM block, 4096 × 16 (256 × 16 for TMS320C26; 8192 × 16 for TMS320C28).
Repeat Counter	RPTC (7–0)	An 8-bit counter to control the repeated execution of a single instruction.
Serial Port Data Receive Register	DRR(15–0)	A 16-bit memory-mapped serial port data receive register. Only the eight LSBs are used in the byte mode.
Serial Port Data Transmit Register	DXR(15–0)	A 16-bit memory-mapped serial port data transmit register. Only the eight LSBs are used in the byte mode.

Table 3–1. TMS320C2x Internal Hardware (Concluded)

Unit	Symbol	Function
Serial Port Receive Shift Register	RSR(15–0)	A 16-bit register used to shift in serial port data from the RX pin. RSR contents are sent to the DRR after a serial transfer is completed. RSR is not directly accessible through software.
Serial Port Transmit Shift Register	XSR(15–0)	A 16-bit register used to shift out serial port data onto the DX pin. XSR contents are loaded from DXR at the beginning of a serial port transmit operation. XSR is not directly accessible through software.
Shifters	—	Shifters are located at the ALU input, the accumulator output, and the product register output. Also, an in-place shifter is located within the accumulator.
Stack	Stack(15–0)	A 4×16 or 8×16 hardware stack used to store the PC during interrupts or calls. The ACCL and data memory values may also be pushed onto and popped from the stack.
Status Registers Temporary Register	ST0,ST1 (15–0)	Two 16-bit status registers that contain status and control bits. A 16-bit register that holds either an operand for the multiplier or a shift code for the scaling shifter.
Temporary Register	TR(15–0)	A 16-bit register that holds either an operand for the multiplier or a shift code for the scaling shifter.
Timer	TIM (15–0)	A 16-bit memory-mapped timer (counter) for timing control.

3.4 Memory Organization

The TMS320C2x provides a total of 544 16-bit words of on-chip data RAM, of which 288 words are always data memory and the remaining 256 words may be configured as either program or data memory. The TMS320C26 provides a total of 1568 words of 16 bit on-chip RAM, divided into four separate bolcks (B0, B1, B2, and B3). The TMS320C25 also provides 4K words of maskable program ROM, while the TMS320E25 provides 4K words of EPROM. This section explains memory management using the on-chip data and program memory, memory maps, memory-mapped registers, auxiliary registers, memory addressing modes, and memory-to-memory moves.

3.4.1 Data Memory

The 544 words of on-chip data RAM are divided into three separate blocks (B0, B1, and B2), as shown in Figure 3–4. Of the 544 words, 256 words (block B0) are configurable as either data or program memory by instructions provided for that purpose; 288 words (blocks B1 and B2) are always data memory. A data memory size of 544 words allows the TMS320C2x to handle a data array of 512 words (256 words if on-chip RAM is used for program memory), while still leaving 32 locations for intermediate storage. See subsection 3.4.3 for memory map configurations.

In the TMS320C26, of the 1568 words, 32 words (block B2) are always data memory, and all other words are programmable as either data or program memory, as shown in Figure 3–5. A data memory size of 1568 words allows the TMS320C26 to handle a data array of 1536 words, while still leaving 32 locations for intermediate storage. When using B0, B1, or B3 as program memory, instructions can be downloaded from external program memory into on-chip RAM, and then executed.

The TMS320C2x can address a total of 64K words of data memory. The on-chip data memory and internally reserved locations are mapped into the lower 1K words of the data memory space. Data memory is directly expandable up to 64K words while still maintaining full-speed operation. A READY line is provided for interface to slower, less expensive memories, such as DRAMs.

3.4.2 Program Memory

On-chip program RAM, ROM/EPROM, or high-speed external program memory can be used at full speed with no wait states. Alternatively, the READY line can interface the TMS320C2x to slower, less expensive external memory. A total of 64K words of memory space is available. Internal RAM block B0 can be configured as program memory using instructions for that purpose. Execution from this block can be initiated after the memory space has been reconfigured. See subsection 3.7.1 for a description of instruction execution using various memory configurations.

Additionally, the TMS320C25 is internally equipped with 4K words of programmable ROM. This on-chip program ROM can be mask programmed at the factory with a customer's program. The TMS320E25 provides a 4K-word, on-chip EPROM. Either on-chip ROM or EPROM allows program execution at full speed without the need for high-speed external program memory. The use of this memory also allows the external data bus to be freed for access of external data memory.

Figure 3–4. TMS320C2x On-Chip Data Memory

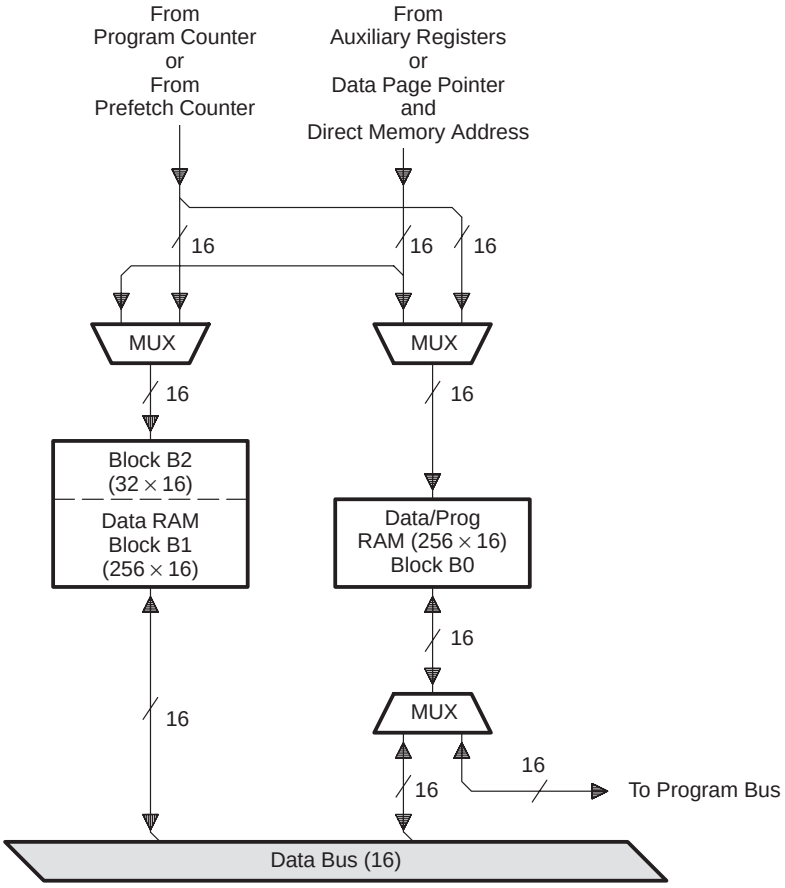
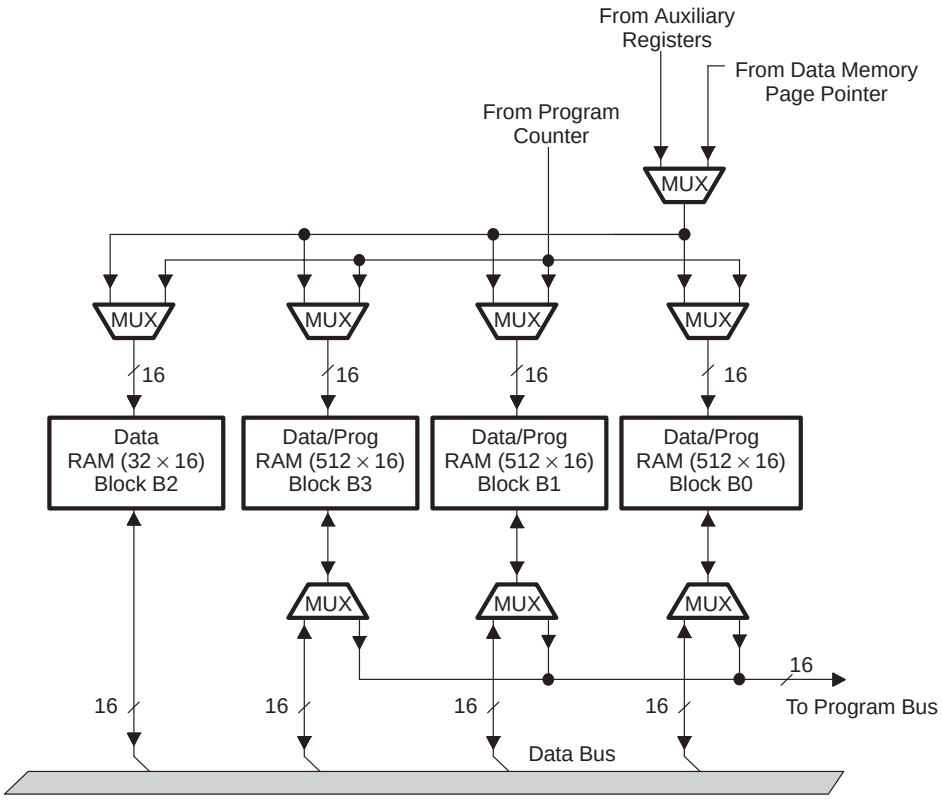


Figure 3–5. TMS320C26 On-Chip Data Memory



Mapping of the first 4K-word block of off-chip/on-chip program memory is user-selectable by means of the MP/$\overline{MC}$ (microprocessor/microcomputer) pin on the TMS320C2x. Setting MP/$\overline{MC}$ to a high maps in the block of off-chip memory; holding the pin at a low maps in the block of on-chip ROM. Consequently, compatible products that depend upon external memory from the ROM can be manufactured in a shorter time frame than the TMS320C2x. Eventually, the off-chip memory device can be replaced by an on-chip memory device at a lower cost because the PC board will not require any modification.

In another mapping technique, the XF (external flag) pin is used to toggle the MP/$\overline{MC}$ pin by dynamically enabling or disabling the on-chip ROM. Note that care must be taken and the instruction pipeline operation (see subsection 3.6.2) must be understood when using this method.

3.4.3 TMS320C2x Memory Maps

The TMS320C2x provides three separate address spaces for program memory, data memory, and I/O, as shown in Figure 3–8. These spaces are distinguished externally by means of the $\overline{PS}$, $\overline{DS}$, and $\overline{IS}$ (program, data, and I/O space select) signals. The $\overline{PS}$, $\overline{DS}$, $\overline{IS}$, and $\overline{STRB}$ signals are active only for external bus accesses. During an internal addressing cycle, these signals remain inactive high, thus preventing conflicts in memory addressing, for example, when block B0 is configured as program memory.

The on-chip memory blocks (B0, B1, and B2) consist of a total of 544 words of RAM. Program/data RAM block B0 (256 words) resides in pages 4 and 5 of the data memory map when configured as data RAM and at addresses 0FF00h to 0FFFFh when configured as program RAM. Block B1 (always data RAM) resides in pages 6 and 7, while block B2 resides in the upper 32 words of page 0. Note that the remainder of page 0 is composed of the memory-mapped registers and internally reserved locations, and pages 1–3 of the data memory map consist of internally reserved locations. The internally reserved locations may not be used for storage, and their contents are undefined when read. See subsection 3.4.4 for further information on the memory-mapped registers.

The on-chip RAM is mapped into either the 64K-word data memory or program memory space, depending on the memory configuration (see Figure 3–5). The CNFD/CNFP instructions are used to configure block B0 as either data or program memory, respectively. The BLKP (block move from program memory to data memory) instruction may be used to download program information to block B0 when it is configured as data RAM. Then a CNFP (configure block as program memory) instruction may be used to convert it to program RAM (see the code example in subsection 5.4.2). Regardless of the configuration, you may still execute from external program memory. Note that when accessing internal program memory, external control lines remain inactive.

Reset configures all internal RAM as data. Note that, due to internal pipelining, when the CNFD or CNFP instruction is used to remap RAM block B0, there is a delay before the new configuration becomes effective. This delay is one fetch cycle if execution is from internal program RAM. On the TMS320C2x, there is a delay of two fetch cycles if execution is from ROM or external program memory. This is particularly important if program execution is from the locations around 0FF00h. Accordingly, a CNFP instruction must be placed at location 0FEFDh in external memory if execution is to continue from the first location in block B0. If a CNFP is placed at location 0FEFDh, and the instruction at location 0FEFFh is a two-word instruction, the second word of the instruction will be fetched from the first location in block B0. If execution is from above location 0FF00h and block B0 is reconfigured, care must be taken to assure that execution resumes at the appropriate point in a new configuration.

The on-chip program ROM can be mapped into the lower 4K words of program memory. This ROM is enabled when MP/$\overline{MC}$ is set to a logic low. To disable the on-chip ROM and use these lower addresses externally, MP/$\overline{MC}$ must be set to a logic high. If all internal RAM blocks are configured as data memory, a program address in the range FF00 to FFFFh accesses external program memory.

3.4.4 TMS320C26 Memory Maps

The memory map of the TMS320C26 is similar to that of the TMS320C25 and is shown in Figure 3–9. The on-chip memory-mapped register and block B2 with 32 words on page 0 are unchanged.

The ROM is reduced to 256 words and contains a multi-purpose bootloader. (See Subsection 5.1.1 and Appendix B.) Additional RAM is included, making the TMS320C26 ideal for many applications.

If the TMS320C26 is in microcomputer mode, the address space from 0 to 0FFFh is internal. External program memory, selected via $\overline{PS}$ (Program Select), can be used starting at address 1000h. The missing space from 0100h to 0FFFh, which would correspond to the larger ROM of the ’C25/E25, is also reserved. If one or more of the blocks B0, B1, or B3 is configured as program memory, the program address space from hexadecimal FA00h to FFFFh is internally reserved for these blocks and can not access external program memory. If all internal RAM blocks are configured as data memory, a program address in the range FA00h to FFFFh accesses external program memory.

The external data memory, selected with $\overline{DS}$ (Data Select), always starts at address 800h (2048 decimal), regardless of the configuration mode of the internal memory.

Because internal memory blocks B0, B1, and B3 (new) are of different size, the internal data memory blocks of the TMS320C26 reside in pages 0 and 4 to 15, while those of the TMS320C25 reside in, pages 0 and 4 to 7. Table 3–2 shows both processors and their internal memory locations. Program memory is also affected by the different block sizes, and the results are given in Table 3–2.

Table 3–2. TMS320C25/26 Memory Blocks

Configured As Data Memory						
TMS320C26				TMS320C25		
Block	**Pages**	**Address Decimal**	**Address Hexadecimal**	**Pages**	**Address Decimal**	**Address Hexadecimal**
B2	0	96–127	0060h–00F7h	0	96–127	0060h–007Fh
B0	4–7	512–1023	0200h–03FFh	4–5	512–768	0200h–02FFh
B1	8–11	1024–1536	0400h–05FFh	6–7	769–1024	0300h–03FFh
B3	12–15	1537–2048	0600h–07FFh	B3 does not exist		
Configured As Program Memory						
TMS320C26				TMS320C25		
Block	**Pages**	**Address Decimal**	**Address Hexadecimal**	**Pages**	**Address Decimal**	**Address Hexadecimal**
B2	B2 is not configurable			B2 is not configurable		
B0	500–503	64000–64511	FA00h–FBFFh	510–511	65280–65535	FF00h–FFFFh
B1	504–507	64512–65023	FC00h–FDFFh	B1 is not configurable		
B3	508–511	65024–65535	FE00h–FFFFh	B3 does not exist		

As shown in Table 3–2 along with Figure 3–6 and Figure 3–7, there is no difference between the TMS320C25/26 data spaces except for the location of memory blocks; therefore, no data memory modification is necessary. However for an internal program (such as relocatable code), the start and stop addresses of each RAM block must be considered.

Figure 3–6. Comparison of Internal RAM Configured as Data Space

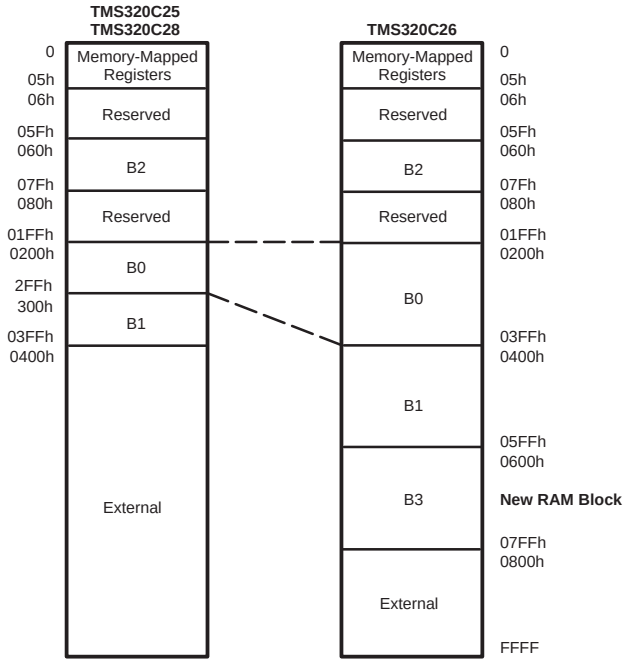


Figure 3–7. Comparison of Internal RAM Configured as Program Space

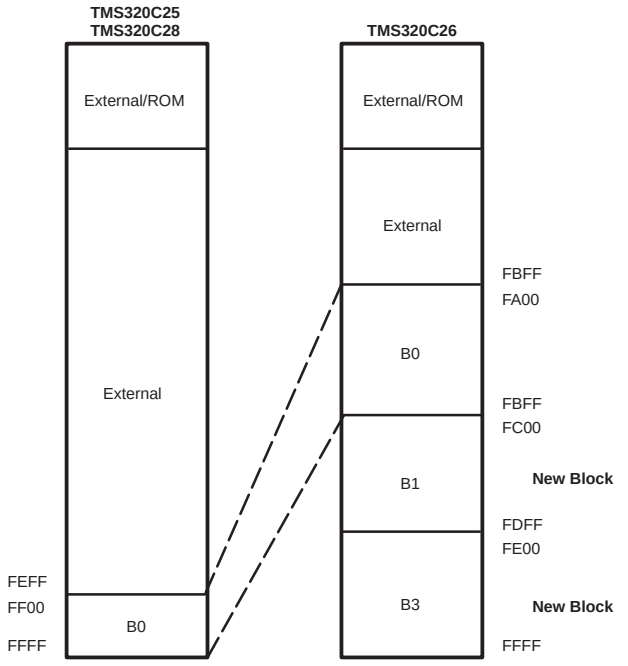


Figure 3–8. TMS320C2x Memory Maps

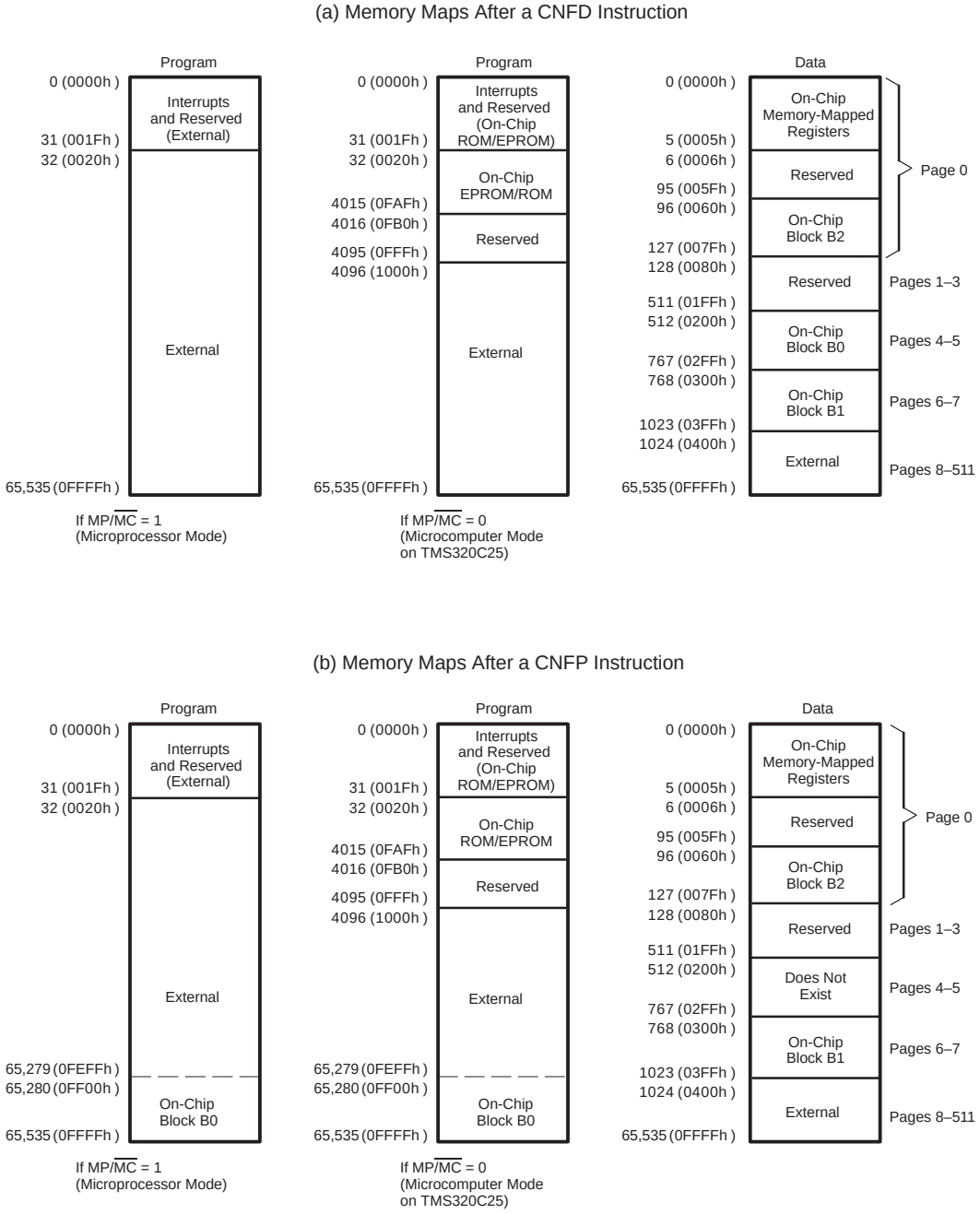
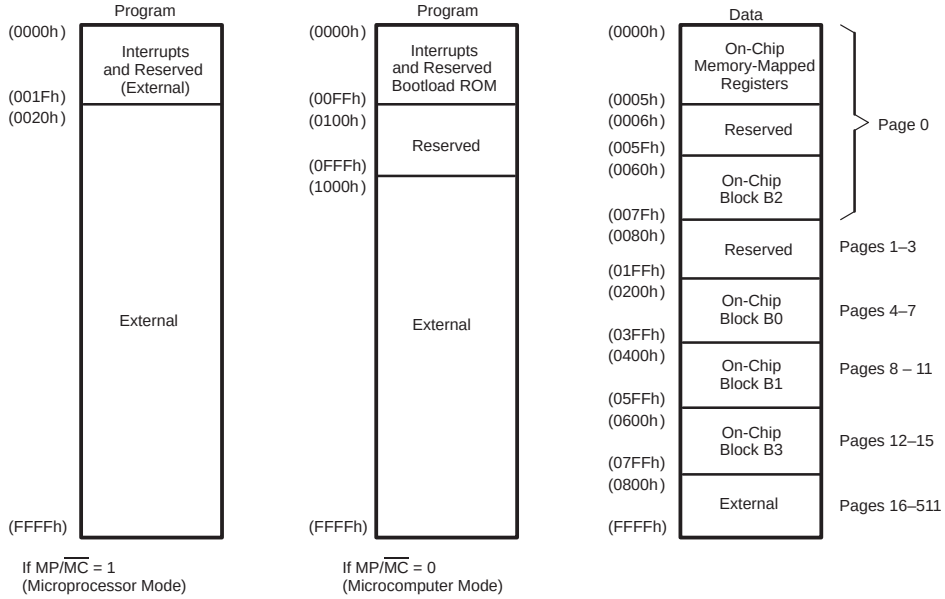
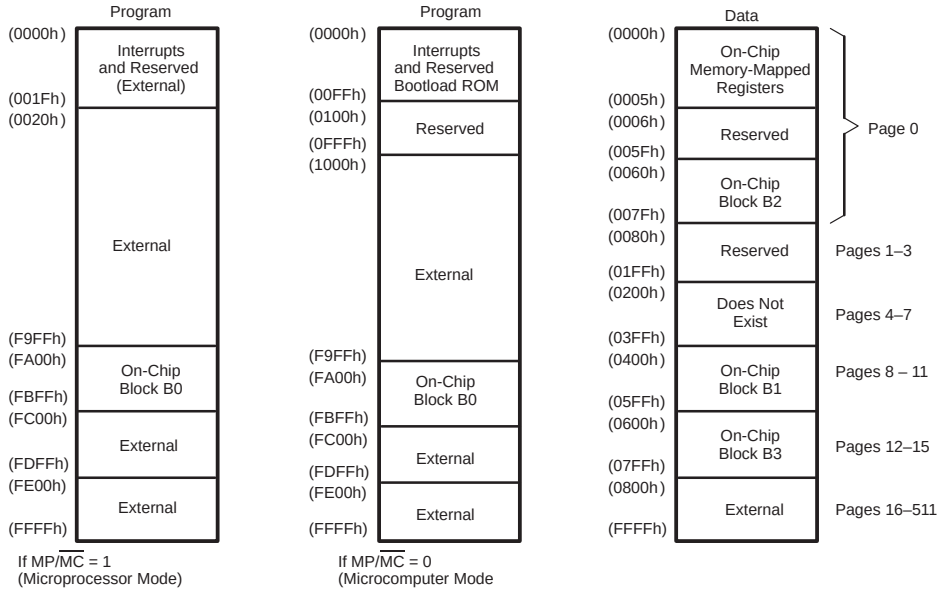


Figure 3–9. TMS320C26 Memory Maps

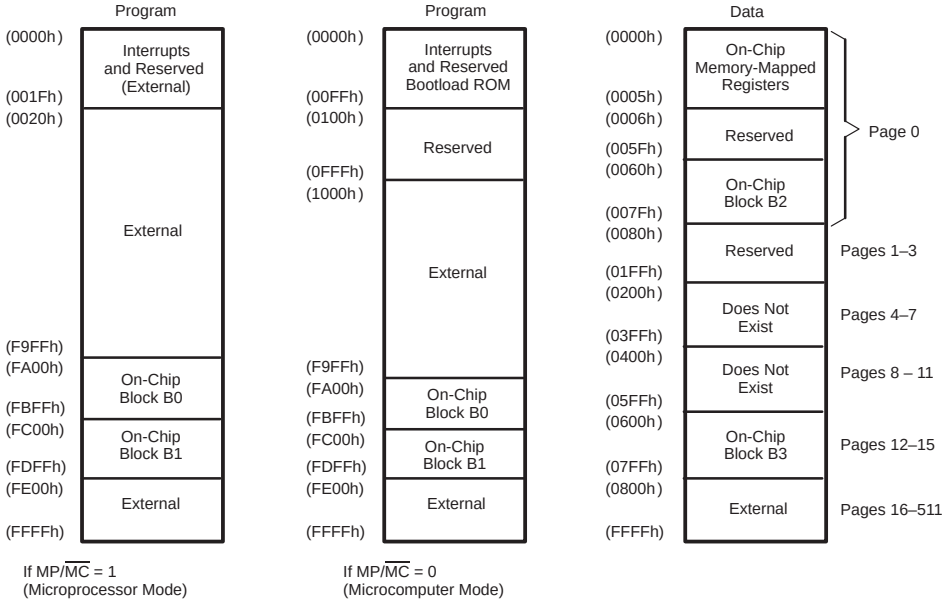


(a) Memory Maps After a CONF 0 Instruction and After Reset

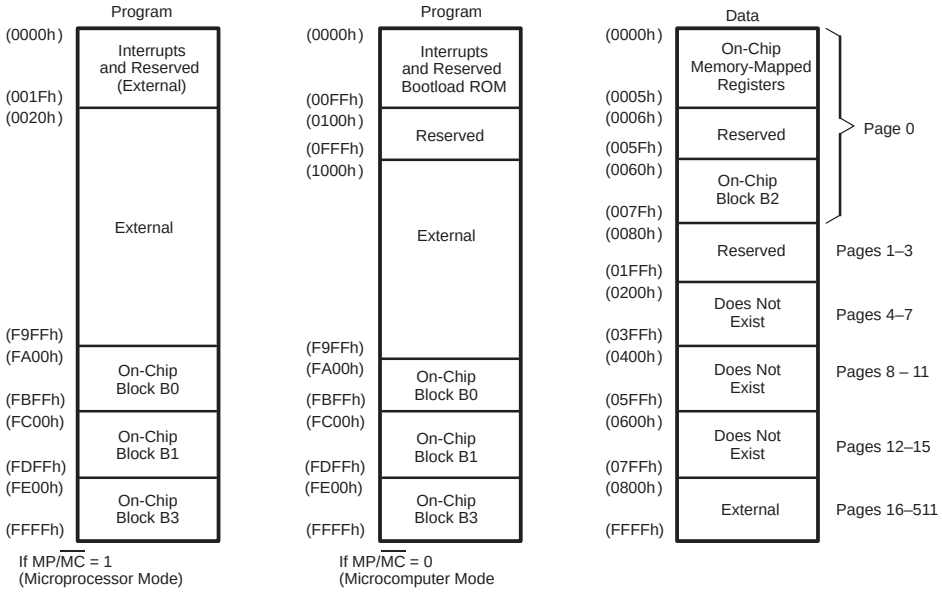


(a) Memory Maps After a CONF 1 Instruction

Figure 3–9. TMS320C26 Memory Maps (continued)



(c) Memory Maps After a CONF 2 Instruction



(d) Memory Maps After a CONF 3 Instruction

3.4.5 Memory-Mapped Registers

The six registers mapped into the data memory space are listed in Table 3–2 and are shown in the block diagram of Figure 3–2.

The memory-mapped registers may be accessed in the same manner as any other data memory location, with the exception that block moves using the BLKD (block move from data memory to data memory) instruction cannot be performed from the memory-mapped registers.

Table 3–3. Memory-Mapped Registers

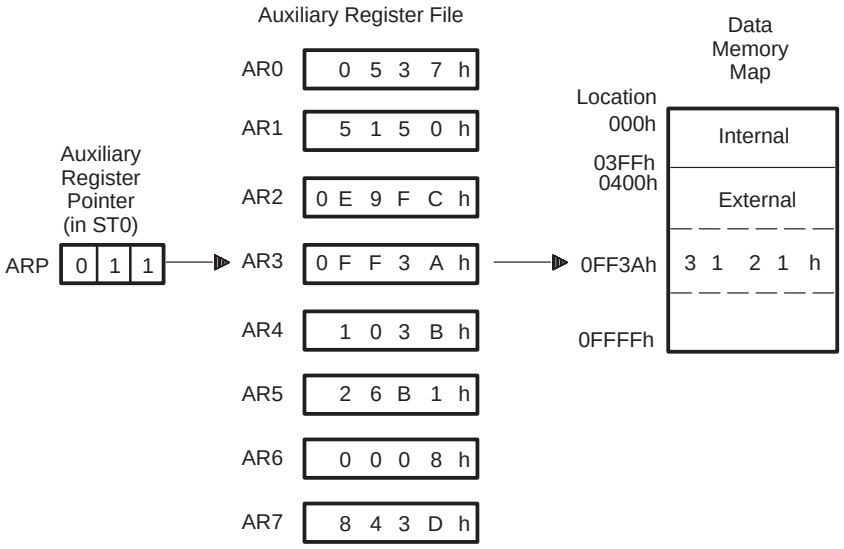
Register Name	Address Location	Definition
DRR(15–0)	0	Serial port data receive register
DXR(15–0)	1	Serial port data transmit register
TIM(15–0)	2	Timer register
PRD(15–0)	3	Period register
IMR (5–0)	4	Interrupt mask register
GREG(7–0)	5	Global memory allocation register

3.4.6 Auxiliary Registers

The TMS320C2x provides a register file containing eight auxiliary registers (AR0–AR7). This section discusses each register's function and how an auxiliary register is selected and stored.

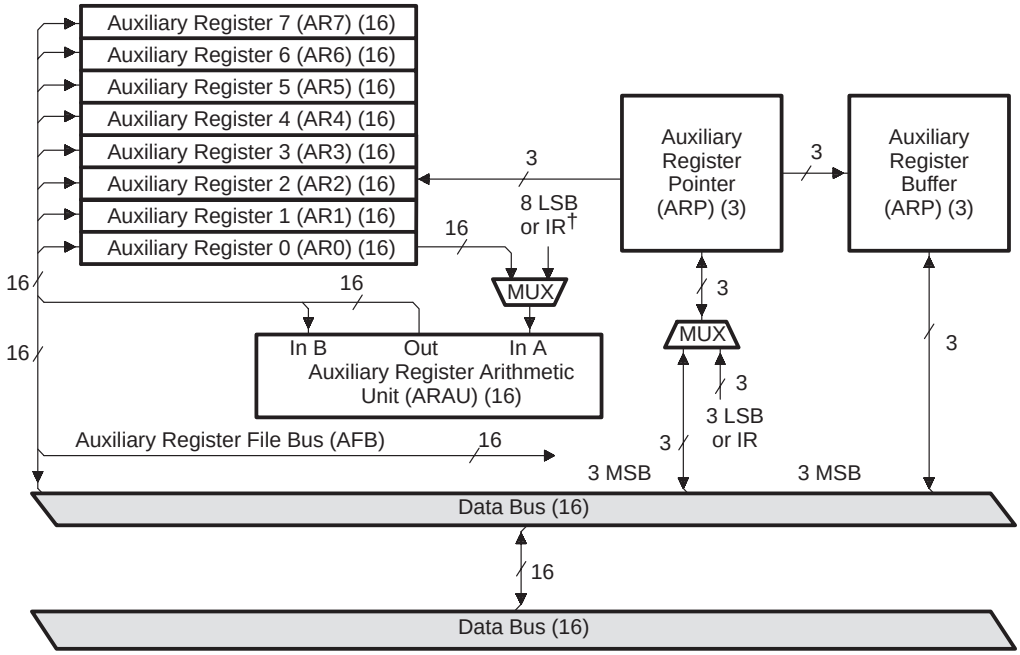
The auxiliary registers may be used for indirect addressing of data memory or for temporary data storage. Indirect auxiliary register addressing (see Figure 4–2) allows placement of the data memory address of an instruction operand into one of the auxiliary registers. These registers are pointed to by a three-bit auxiliary register pointer (ARP) that is loaded with a value from 0 through 7, designating AR0 through AR7, respectively. The auxiliary registers and the ARP may be loaded either from data memory or by an immediate operand defined in the instruction. The contents of these registers may also be stored in data memory. (Chapter 4 describes the programming of the indirect addressing mode.)

Figure 3–10. Indirect Auxiliary Register Addressing Example



The auxiliary register files (AR0–AR7 on the TMS320C2x) are connected to the auxiliary register arithmetic unit (ARAU), shown in Figure 3–11. The ARAU may autoindex the current auxiliary register while the data memory location is being addressed. Indexing by either 1 or by the contents of AR0 may be performed. As a result, accessing tables of information does not require the central arithmetic logic unit (CALU) for address manipulation, thus freeing it for other operations.

Figure 3–11. Auxiliary Register File



As shown in Figure 3–11, auxiliary register 0 (AR0) or the eight LSBs of the instruction registers can be connected to one of the inputs of the ARAU. The other input is fed by the current AR (being pointed to by ARP). AR(ARP) refers to the contents of the current AR pointed to by ARP. The ARAU performs the following functions:

AR(ARP) + AR0 → AR(ARP)	Index the current AR by adding a 16-bit integer contained in AR0.
AR(ARP) – AR0 → AR(ARP)	Index the current AR by subtracting a 16-bit integer contained in AR0.
AR(ARP) + 1 → AR(ARP)	Increment the current AR by one.
AR(ARP) – 1 → AR(ARP)	Decrement the current AR by one.
AR(ARP) → AR(ARP)	AR(ARP) is unchanged.

In addition to the above functions, the ARAU on the TMS320C25 performs functions as follows:

AR(ARP) + IR(7–0) → AR(ARP)	Add 8-bit immediate value to the current AR.
AR(ARP) – IR(7 – 0) → AR(ARP)	Subtract 8-bit immediate value to the current AR.

AR(ARP) + rcAR0 → AR(ARP)	Bit-reversed indexing, add AR0 with reverse-carry (rc) propagation (see subsection 4.1.2)
AR(ARP) – rcAR0 → AR(ARP)	Bit-reversed indexing, subtract AR0 with reverse-carry (rc) propagation (see subsection 4.1.2).

Although the ARAU is useful for address manipulation in parallel with other operations, it may also serve as an additional general-purpose arithmetic unit, since the auxiliary register file can directly communicate with data memory. The ARAU implements 16-bit unsigned arithmetic, whereas the CALU implements 32-bit 2s-complement arithmetic. Instructions provide branches dependent on the comparison of the auxiliary register pointed to by ARP with AR0. The BANZ instruction permits the auxiliary registers to be used also as loop counters.

The three-bit auxiliary register pointer buffer (ARB), shown in Figure 3–8, provides storage for the ARP on subroutine calls and interrupts.

3.4.7 Memory Addressing Modes

The TMS320C2x can address a total of 64K words of program memory and 64K words of data memory. The on-chip data memory is mapped into the 64K-word data memory space. The on-chip ROM in the TMS320C25 is mapped into the program memory space when in the microcomputer mode. The memory maps, which change with the configuration of block B0, B1, and B3, are described in detail in subsections 3.4.3 and 3.4.4.

The 16-bit data address bus (DAB) addresses data memory in one of the following two ways:

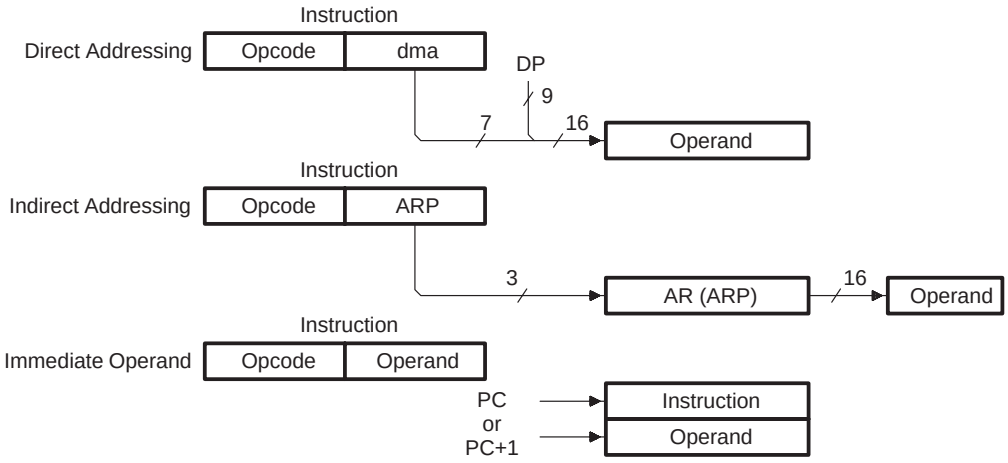
1) By the direct address bus (DRB) using the direct addressing mode (for example, ADD 10h), or

2) By the auxiliary register file bus (AFB) using the indirect addressing mode (for example, ADD *).

Operands are also addressed by the contents of the program counter in the immediate addressing mode.

Figure 3–12 illustrates operand addressing in the direct, indirect, and immediate addressing modes.

Figure 3–12. Methods of Instruction Operand Addressing



In the direct addressing mode, the 9-bit data memory page pointer (DP) points to one of 512 pages, each page consisting of 128 words. The data memory address (dma), specified by the seven LSBs of the instruction, points to the desired word within the page. The address on the direct address bus (DRB) is formed by concatenating the 9-bit DP with the 7-bit dma.

In the indirect addressing mode, the currently selected 16-bit auxiliary register AR(ARP) addresses the data memory through the auxiliary register file bus (AFB). While the selected auxiliary register provides the data memory address and the data is being manipulated by the CALU, the contents of the auxiliary register may be manipulated through the ARAU. See Figure 3–12 for an example of indirect auxiliary register addressing. The direct and indirect addressing modes are described in detail in Section 4.1.

When an immediate operand is used, it is contained either within the instruction word itself or, in the case of 16-bit immediate operands, in the word following the instruction opcode.

3.4.8 Memory-to-Memory Moves

The TMS320C2x provides instructions for data and program block moves and for data move functions that efficiently utilize the configurable on-chip RAM.

The BLKD instruction moves a block within data memory, and the BLKP instruction moves a block from program memory to data memory. When used with the repeat instructions (RPT/RPTK), the BLKD/BLKP instructions efficiently perform block moves from on- or off-chip memory.

Implemented in on-chip RAM, the DMOV (data move) function on the TMS320C2x is equivalent to that of the TMS320C1x. DMOV allows a word to be copied from the currently addressed data memory location in on-chip RAM to the next higher location while the data from the addressed location is being operated upon in the same cycle (for example, by the CALU). An ARAU operation may also be performed in the same cycle when using the indirect addressing mode. The DMOV function is useful for implementing algorithms that use the z^{-1} delay operation, such as convolutions and digital filtering where data is being passed through a time window. The data move function can be used anywhere within blocks B0, B1, and B2 (and block B3 with the TMS320C26). It is continuous across the boundary of blocks B0 and B1 but cannot be used with off-chip data memory. The MACD (multiply and accumulate with data move) and the LTD (load T register, accumulate previous product, and move data) instructions use the data move function.

The TBLR/TBLW (table read/write) instructions allow words to be transferred between program and data spaces. TBLR is used to read words from on-chip ROM or off-chip program ROM/RAM into the data RAM. TBLW is used to write words from on-chip data RAM to off-chip program RAM.

3.5 Central Arithmetic Logic Unit (CALU)

The TMS320C2x central arithmetic logic unit (CALU) contains a 16-bit scaling shifter, a 16 × 16-bit parallel multiplier, a 32-bit arithmetic logic unit (ALU), a 32-bit accumulator (ACC), and additional shifters at the outputs of both the accumulator and the multiplier. This section describes the CALU components and their functions. Figure 3–13 is a block diagram showing the components of the CALU. In the figure, note that SFL and SFR indicate shifts to the left or right, respectively.

The following steps occur in the implementation of a typical ALU instruction:

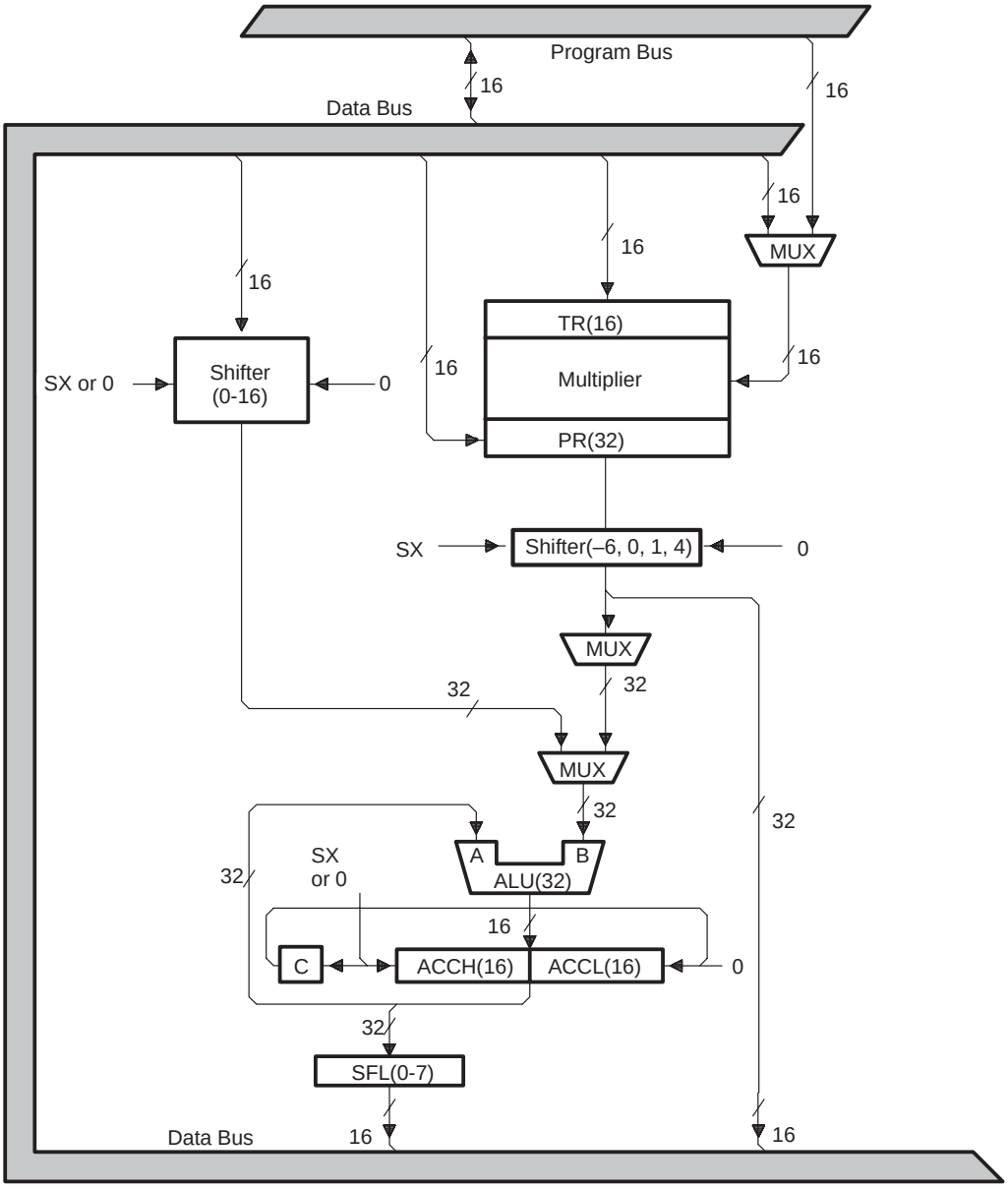
1) Data is fetched from the RAM on the data bus,

2) Data is passed through the scaling shifter and the ALU where the arithmetic is performed, and

3) The result is moved into the accumulator.

One input to the ALU is always provided from the accumulator, and the other input may be transferred from the product register (PR) of the multiplier or from the scaling shifter that is loaded from data memory.

Figure 3–13. Central Arithmetic Logic Unit (CALU), TMS320C2x



3.5.1 Scaling Shifter

The TMS320C2x provides a scaling shifter that has a 16-bit input connected to the data bus and a 32-bit output connected to the ALU (see Figure 3–13). The scaling shifter produces a left shift of 0 to 16 bits on the input data, as programmed in the instruction. The LSBs of the output are filled with zeros, and the MSBs may be either filled with zeros or sign-extended, depending upon the status programmed into the SXM (sign-extension mode) bit of status register ST1.

The TMS320C2x also contains several other shifters, which allow it to perform numerical scaling, bit extraction, extended-precision arithmetic, and overflow prevention. These shifters are connected to the output of the multiplier and the accumulator.

3.5.2 ALU and Accumulator

The TMS320C2x 32-bit ALU and accumulator implement a wide range of arithmetic and logical functions, the majority of which execute in a single clock cycle. Once an operation is performed in the ALU, the result is transferred to the accumulator where additional operations such as shifting may occur. Data that is input to the ALU may be scaled by the scaling shifter.

The ALU is a general-purpose arithmetic unit that operates on 16-bit words taken from data RAM or derived from immediate instructions. In addition to the usual arithmetic instructions, the ALU can perform Boolean operations that make possible the bit manipulation required of a high-speed controller. One input to the ALU is always provided from the accumulator, and the other input may be provided from the product register (PR) of the multiplier or the input scaling shifter that has fetched data from the RAM on the data bus. After the ALU has performed the arithmetic or logical operations, the result is stored in the accumulator.

The 32-bit accumulator (see Figure 3–13) is split into two 16-bit segments for storage in data memory: ACCH (accumulator high) and ACCL (accumulator low). Shifters at the output of the accumulator provide a left-shift of 0 to 7 places on the TMS320C2x. This shift is performed while the data is being transferred to the data bus for storage. The contents of the accumulator remain unchanged. When the ACCH data is shifted left, the LSBs are transferred from the ACCL, and the MSBs are lost. When ACCL is shifted left, the LSBs are zero-filled, and the MSBs are lost.

The TMS320C2x supports floating-point operations for applications requiring a large dynamic range. The NORM (normalization) instruction performs left shifts to normalize fixed-point numbers contained in the accumulator. The LACT (load accumulator with shift specified by the T register) instruction denormalizes a floating-point number by arithmetically left-shifting the mantissa through the input scaling shifter. The shift count, in this case, is the value of

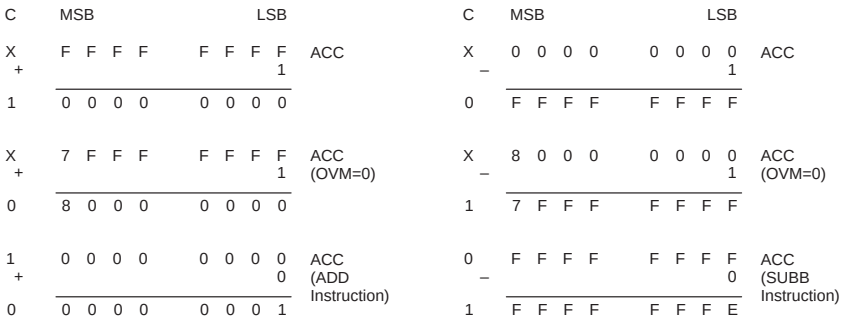
the exponent specified by the four low-order bits of the T register (TR). ADDT and SUBT (add to/subtract from accumulator with shift specified by the T register) instructions have also been provided to allow additional arithmetic operations.

The accumulator overflow saturation mode may be programmed through the SOVM and ROVM (set/reset overflow mode) instructions. When the accumulator is in the overflow saturation mode and an overflow occurs, the overflow flag is set and the accumulator is loaded with either the most positive or the most negative number, depending upon the direction of overflow. The value of the accumulator upon saturation is 7FFFFFFFh (positive) or 80000000h (negative). If the OVM (overflow mode) status register bit is reset and an overflow occurs, the overflowed results are loaded into the accumulator without modification. (Note that logical operations cannot result in overflow.)

The TMS320C2x can execute a variety of branch instructions that depend on the status of the ALU and accumulator. These instructions include the BV (branch on overflow) and BZ (branch on accumulator equal to zero). In addition, the BACC (branch to address in accumulator) instruction provides the ability to branch to an address specified by the accumulator. Bit test instructions (BIT and BITT), which do not affect the accumulator, allow the testing of a specified bit of a word in data memory.

The accumulator on the TMS320C25 also has an associated carry bit that is set or reset, depending on various operations within the device. The carry bit allows more efficient computation of extended-precision products and additions or subtractions. It is also useful in overflow management. The carry bit is affected by most arithmetic instructions as well as the shift and rotate instructions. It is not affected by loading the accumulator, logical operations, or other such nonarithmetic or control instructions. It is also not affected by the multiply (MPY, MPYK, and MPYU) instructions, but is affected by the accumulation process in the MAC and MACD instructions. Examples of carry bit operation are shown in Figure 3–14.

Figure 3–14. Examples of TMS320C25 Carry Bit Operation


C MSB LSB
X F F F F F F F F ACC
+ 1
1 0 0 0 0 0 0 0 0
X 7 F F F F F F F F ACC
+ 1 (OVM=0)
0 8 0 0 0 0 0 0 0 0
1 0 0 0 0 0 0 0 0 0 ACC
+ 0 (ADD
0 0 0 0 0 0 0 0 1 Instruction)
C MSB LSB
X 0 0 0 0 0 0 0 0 0 ACC
– 1
0 F F F F F F F F
X 8 0 0 0 0 0 0 0 0 ACC
– 1 (OVM=0)
1 7 F F F F F F F F
0 F F F F F F F F 0 ACC
– 0 (SUBB
1 F F F F F F F E Instruction)

The value added to or subtracted from the accumulator, shown in the examples of Figure 3–14, may come from either the input scaling shifter or the shifter at the output of the P register. The carry bit is set if the result of an addition or accumulation process generates a carry; it is reset to zero if the result of a subtraction generates a borrow. Otherwise, it is reset after an addition or set after a subtraction.

The ADDC (add to accumulator with carry) and SUBB (subtract from accumulator with borrow) instructions provided on the TMS320C25 use the previous value of carry in their addition/subtraction operation (see these instructions in Chapter 4 for more detailed information).

The one exception to operation of the carry bit, as shown in Figure 3–14, is in the use of the ADDH (add to high accumulator) and SUBH (subtract from high accumulator) instructions. The ADDH instruction can set the carry bit only if a carry is generated, and the SUBH instruction can reset the carry bit only if a borrow is generated; otherwise, neither instruction can affect it.

Two branch instructions, BC and BNC, can execute branching on the status of the carry bit. The SC, RC, and LST1 instructions can also be used to load the carry bit. The carry bit is set to one on a hardware reset.

The SFL and SFR (in-place one-bit shift to the left/right) instructions on the TMS320C2x and the ROL and ROR (rotate to the left/right) instructions on the TMS320C25 implement shifting or rotating of the contents of the accumulator through the carry bit. The SXM bit affects the definition of the SFR (shift accumulator right) instruction. When SXM = 1, SFR performs an arithmetic right shift, maintaining the sign of the accumulator data. When SXM = 0, SFR performs a logical shift, shifting out the LSB and shifting in a zero for the MSB. The SFL (shift accumulator left) instruction is not affected by the SXM bit and behaves the same in both cases, shifting out the MSB and shifting in a zero. Repeat (RPT or RPTK) instructions may be used with the shift and rotate instructions for multiple shift counts.

3.5.3 Multiplier, T and P Registers

The TMS320C2x utilizes a 16 $\times$ 16-bit hardware multiplier, which is capable of computing a signed or unsigned 32-bit product in a single machine cycle. All multiply instructions, except the MPYU (multiply unsigned) instruction on the TMS320C25, perform a signed multiply operation in the multiplier. That is, the two numbers being multiplied are treated as 2s complement numbers, and the result is a 32-bit 2s complement number. As shown in Figure 3–13, the following two registers are associated with the multiplier:

- A 16-bit temporary register (TR) that holds one of the operands for the multiplier,
- A 32-bit product register (PR) that holds the product.

The output of the product register can be left-shifted 1 or 4 bits. This is useful for implementing fractional arithmetic or justifying fractional products. The output of the PR can also be right-shifted 6 bits to enable the execution of up to 128 consecutive multiply/accumulates without the possibility of overflow.

An LT (load T register) instruction normally loads the TR to provide one operand (from the data bus), and the MPY (multiply) instruction provides the second operand (also from the data bus). A multiplication can also be performed with an immediate operand using the MPYK instruction. In either case, a product can be obtained every two cycles.

Two multiply/accumulate instructions (MAC and MACD) fully utilize the computational bandwidth of the multiplier, allowing both operands to be processed simultaneously. The data for these operations may reside anywhere in internal or external memory or can be transferred to the multiplier each cycle via the program and data buses. This provides for single-cycle multiply/accumulates when used with repeat (RPT/RPTK) instructions. Note that the DMOV portion of the MACD instruction will not function with external data memory addresses. On the TMS320C2x, the MAC and MACD instructions can be used with both operands in either internal or external memory or one each in on-chip RAM. The SQRA (square/add) and SQRS (square/subtract) instructions pass the same value to both inputs of the multiplier for squaring a data memory value.

The MPYU instruction on the TMS320C2x performs an unsigned multiplication, which greatly facilitates extended-precision arithmetic operations. The unsigned contents of the T register are multiplied by the unsigned contents of the addressed data memory location, with the result placed in the P register. This allows operands of greater than 16 bits to be broken down into 16-bit words and processed separately to generate products of greater than 32 bits.

After the multiplication of two 16-bit numbers, the 32-bit product is loaded into the PR on the TMS320C2x. The product from the PR may be transferred to the ALU.

Four product shift modes (PM) are available at the PR output and are useful when performing multiply/accumulate operations and fractional arithmetic, or when justifying fractional products. The PM field of status register ST1 specifies the PM shift mode, as shown in Table 3–4.

Table 3–4. PM Shift Modes

If PM Is:	Result
00	No shift
01	Left shift of 1 bit
10	Left shift of 4 bits
11	Right shift of 6 bits

Left shifts specified by the PM value are useful for implementing fractional arithmetic or justifying fractional products. For example, the product of either two normalized, 16-bit, 2s-complement numbers or two Q15 numbers contains two sign bits, one of which is redundant. Q15 format, one of the various types of Q format, is a number representation commonly used when performing operations on noninteger numbers (see subsection 5.6.7 for an explanation and examples of Q15 representation). The single-bit left shift eliminates this extra sign bit from the product when it is transferred to the accumulator. This results in the accumulator contents being formatted in the same manner as the multiplicands. Similarly, the product of either a normalized, 16-bit, 2s-complement or Q15 number and a 13-bit, 2s-complement constant contains five sign bits, four of which are redundant. This is the case, for example, when using the MPYK instruction. Here the four-bit shift properly aligns the result as it is transferred to the accumulator.

Using the right-shift PM value allows the execution of up to 128 consecutive multiply/accumulate operations without the threat of an arithmetic overflow, thereby avoiding the overhead of overflow management. The shifter can be disabled to cause no shift in the product when working with integer or 32-bit precision operations. This allows compatibility with TMS320C1x code to be maintained. Note that the PM right shift is always sign-extended, regardless of the state of SXM.

The four least significant bits of the T register (TR) also define a variable shift through the scaling shifter for the LACT/ADDT/SUBT (load/add-to/subtract-from accumulator with shift specified by the TR) instructions. These instructions are useful in floating-point arithmetic where a number needs to be denormalized, that is, floating-point to fixed-point conversion. The BITT (bit test) instruction allows testing of a single bit of a word in data memory based on the value contained in the four LSBs of the TR.

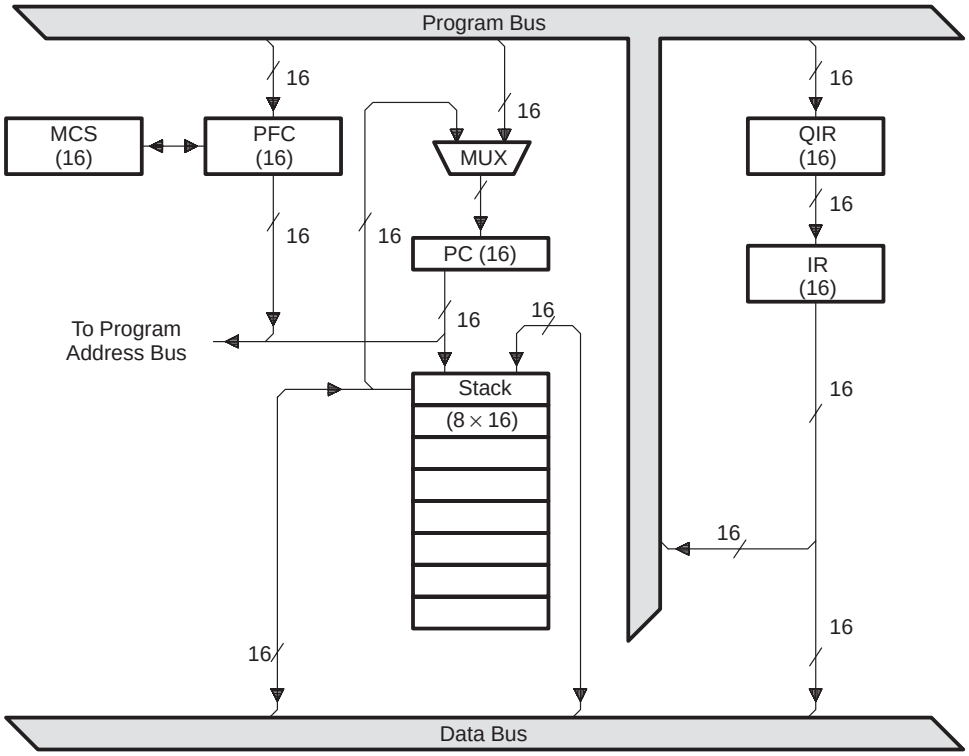
3.6 System Control

System control on the TMS320C2x is supported by the program counter, hardware stack, PC-related hardware, the external reset signal, interrupts (see Section 3.8), the status registers, the on-chip timer, and the repeat counter. The following sections describe the function of each of these components in system control and pipeline operation.

3.6.1 Program Counter and Stack

The TMS320C2x contains a 16-bit program counter (PC) and a hardware stack of eight locations for PC storage (see Figure 3–15). The program counter addresses internal and external program memory in fetching instructions. The stack is used during interrupts and subroutines.

Figure 3–15. Program Counter, Stack, and Related Hardware



The program counter addresses program memory, either on-chip or off-chip, via the program address bus (PAB). Through the PAB, an instruction is fetched from program memory and loaded into the instruction register (IR). When the IR is loaded, the PC is ready to start the next instruction fetch cycle. The PC may address any on-chip RAM blocks configured as program memory, or the

on-chip ROM provided on the TMS320C25. The PC also addresses off-chip program memory through the external address bus A15–A0 and the external data bus D15–D0.

Data memory is addressed by the program counter during a BLKD instruction, which moves data blocks from one section of data memory to another. The contents of the accumulator may be loaded into the PC to implement computed GOTO operations. This can be accomplished using the BACC (branch to address in accumulator) or CALA (call subroutine indirect) instructions.

To start a new fetch cycle, the PC is loaded either with PC+1 or with a branch address (for instructions such as branches, calls, or interrupts). In the case of conditional branches where the branch is not taken, the PC is incremented once more beyond the location of the branch address.

The TMS320C2x also has a feature that allows the execution of the next single instruction N+1 times. N is defined by loading an 8-bit counter RPTC (repeat counter). If this repeat feature is used, the instruction is executed, and the RPTC is decremented until the RPTC goes to zero. This feature is useful with many instructions, such as NORM (normalize contents of accumulator), MACD (multiply and accumulate with data move), and SUBC (conditional subtract). When used with some multicycle instructions, such as MACD, the repeat features can result in these instructions effectively executing in a single cycle.

The stack is 16 bits wide and eight levels deep. The PC stack is accessible through the use of the PUSH and POP instructions. Whenever the contents of the PC are pushed onto the top of the stack, the previous contents of each level are pushed down, and the bottom (eighth) location of the stack is lost. Therefore, data will be lost if more than eight successive pushes occur before a pop. The reverse happens on pop operations. Any pop after seven sequential pops yields the value at the bottom stack level. All of the stack levels then contain the same value. Two additional instructions, PSHD and POPD, push a data memory value onto the stack or pop a value from the stack to data memory. These instructions allow a stack to be built in data memory for the nesting of subroutines/interrupts beyond four/eight levels.

Note that on the TMS320C2x, the TBLR/TBLW, MAC/MACD, and BLKD/BLKP instructions use a separate stack, MCS (microcall stack); no level of the PC stack is used.

3.6.2 Pipeline Operation

Instruction pipelining consists of the sequence of external bus operations that occurs during instruction execution. The prefetch-decode-execute pipeline is essentially invisible to the user, except in some cases where the pipeline must be broken (such as for branch instructions). In the operation of the pipeline, the prefetch, decode, and execute operations are independent, which allows instruction executions to overlap. Thus, during any given cycle, three different instructions can be active, each at a different stage of completion, resulting in the three-level pipeline on the TMS320C2x.

The difference in pipeline levels does not necessarily affect instruction execution speed, but merely changes the fetch/decode sequence. Most instructions execute in the same number of cycles, regardless of whether they are executed from internal RAM, ROM, or external program memory. The effects of pipelining are included in the instruction cycle timings for the TMS320C25 listed in Appendix D.

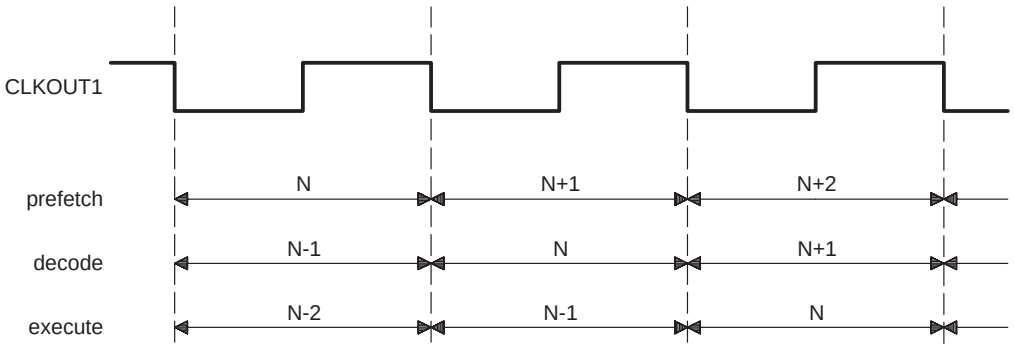
Additional PC-related hardware (see Figure 3–15) is provided on the TMS320C25 to allow three-level pipelining for higher performance. Included in the related hardware are the prefetch counter (PFC), the 16-bit microcall stack (MCS) register, the instruction register (IR), and the queue instruction register (QIR).

In the three-level pipeline on the TMS320C25, the PFC contains the address of the next instruction to be prefetched. Once an instruction is prefetched, the instruction is loaded into the IR, unless the IR still contains an instruction currently executing, in which case the prefetched instruction is stored in the QIR. The PFC is then incremented, and after the current instruction has completed execution, the instruction in the QIR is loaded into the IR to be executed.

The PC contains the address of the next instruction to be executed and is not used directly in instruction fetch operations, but merely serves as a reference pointer to the current position within the program. The PC is incremented as each instruction is executed. When interrupts or subroutine call instructions occur, the contents of the PC are pushed onto the stack to preserve return linkage to the previous program context.

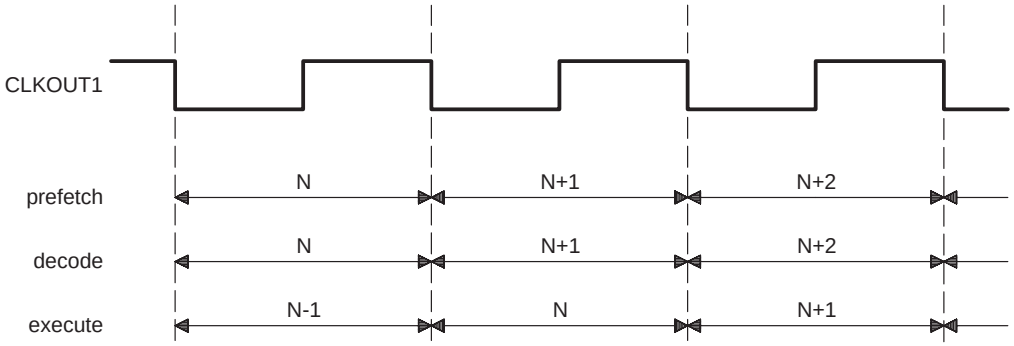
The prefetch, decode, and execute operations of the pipeline are independent, thus allowing instruction executions to overlap. During any given cycle, three different instructions can be active, each at a different stage of completion. Figure 3–16 shows the operation of the three-level pipeline for single-word, single-cycle instructions executing from either internal program ROM or external memory with no wait states.

Figure 3–16. Three-Level Pipeline Operation (TMS320C25)



Pipelining is reduced to two levels when execution is from internal program RAM due to the fact that an instruction in internal RAM can be fetched and decoded in the same cycle. Thus, separate prefetch and decode operations are not required, as shown in Figure 3–17.

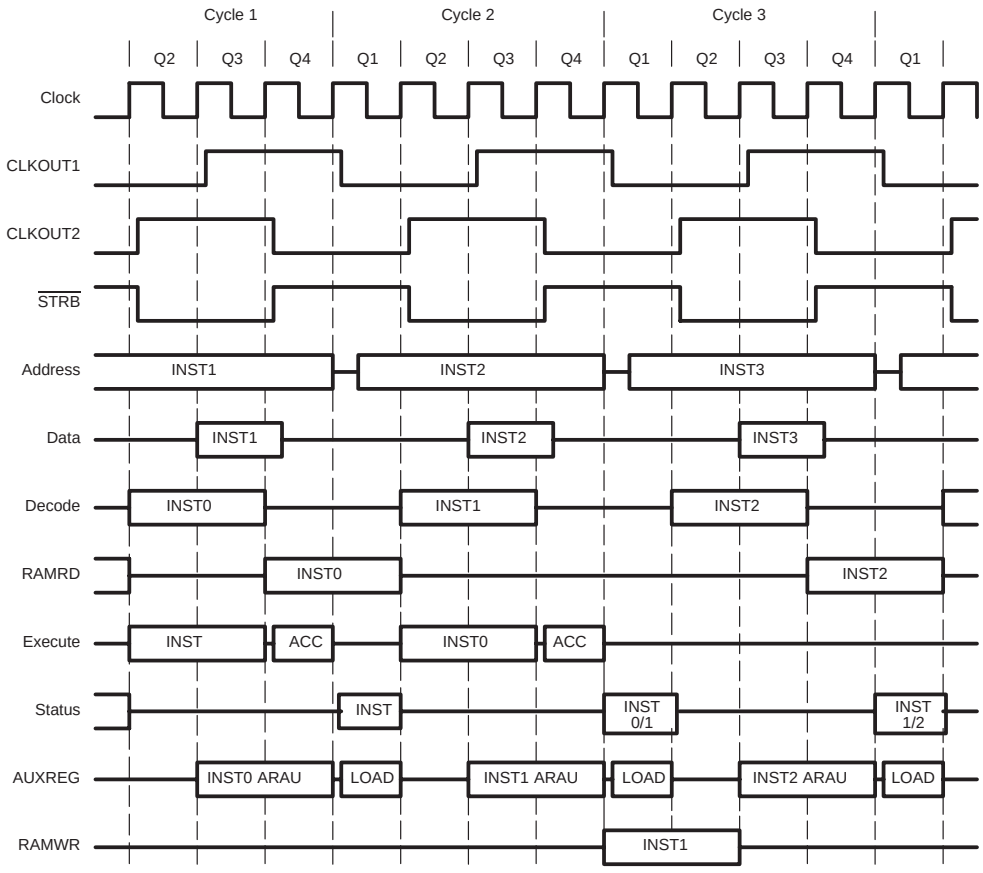
Figure 3–17. Two-Level Pipeline Operation



The following paragraphs describe, in detail, the operation of the TMS320C25 pipeline. This description, in conjunction with Appendix D, gives sufficient information for predicting the operation of the TMS320C25 for hardware interface optimization, accurate program cycle counting, and simulation modelling. Often, it is not necessary to understand the intricate detail of the pipeline to design with the TMS320C25. Therefore, if you are not specifically interested in these details, you can skip this description.

The TMS320C25 executes most of its instructions in a single cycle because all the instructions are straight decodes and highly pipelined as opposed to microcode. The basic pipeline operation is 3.25 cycles deep where the device sequence on any given cycle is fetching the third instruction, decoding the second instruction, and executing the first. Figure 3–18 shows the internal operation of the TMS320C25 pipeline in reference to quarter phases 1 through 4 (Q1–Q4).

Figure 3–18. TMS320C25 Standard Pipeline Operation



The TMS320C25 machine cycle, externally referenced by the falling edges of the CLKOUT1 signal, consists of four internal cycles (or CLKIN cycles). This allows internal operations of the pipeline to execute as fast as 1/4 the machine cycle. The sequence of a general instruction execution in the pipeline is shown in Table 3–5.

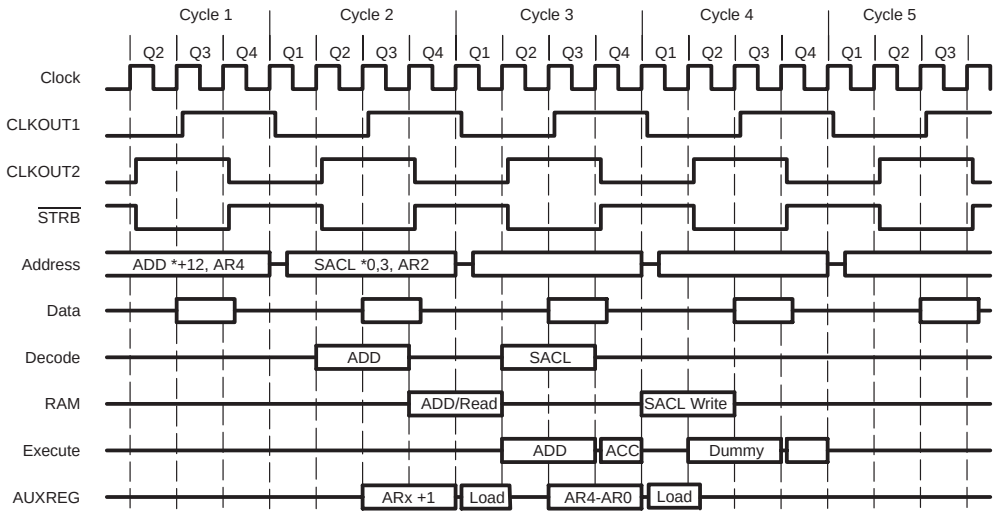
Table 3–5. Instruction Pipeline Sequence

Cycle	Q Phase	Operation
1	1 2 3 4	New PC is output on address bus External read of instruction External read of instruction External read of instruction
2	1 2 3 4	 Instruction decode Instruction decode/ARAU execution On-chip RAM access/ARAU execution
3	1 2 3 4	On-chip RAM access/load new AR value/update ARP ALU execution ALU execution Load accumulator
4	1	Load status register

When using an add instruction (for example, ADD *+,12,AR4), the device fetches the instruction in cycle 1. During Q2 and Q3 of cycle 2, the instruction is decoded. This includes the ALU command decode as well as generation of the data operand fetch address. In this case, the address comes from an auxiliary register. During Q4 of cycle 2 and Q1 of cycle 3, the operand is fetched from the RAM location. The increment of the auxiliary register is performed during Q3 and Q4 of cycle 2, and the value is loaded into the auxiliary register in Q1 of cycle 3. The ARP is also updated in Q1 of cycle 3. During Q2 and Q3 of cycle 3, the data is passed through the barrel shifter to execute the 12-bit left-shift, and the data is added by the ALU to the contents in the accumulator. In Q4 of the third cycle, the ALU result is loaded into the accumulator. The status of the ALU operation is loaded into the status register in Q1 of the fourth cycle. The bits being loaded into the status register at this time consist of the current ALU status and the ARP associated with the next instruction.

In the case of a store instruction (for example, SACL *0–,3,AR2), the device operates the first two cycles in the same manner as the ADD instruction. In Q1 and Q2 of the third cycle, the data in the accumulator is passed through a barrel shifter, left-shifted 3 bits, and zero-filled. The lower 16 bits of the shifted value are written to the address specified by the current auxiliary register. During Q3 and Q4 of the third cycle, the index register (AR0) is added to the contents of the current auxiliary register and loaded back into the current auxiliary register in Q1 of the fourth phase. In Q1 of the fourth cycle, the auxiliary register pointer is changed to AR2. There is no execution phase of this instruction. Figure 3–19 shows the ADD and SACL instructions operating back-to-back in a program sequence. It is assumed that both instructions reside in external, zero wait-state memory and that the data resides in on-chip RAM.

Figure 3–19. Pipeline Operation of ADD Followed by SACL

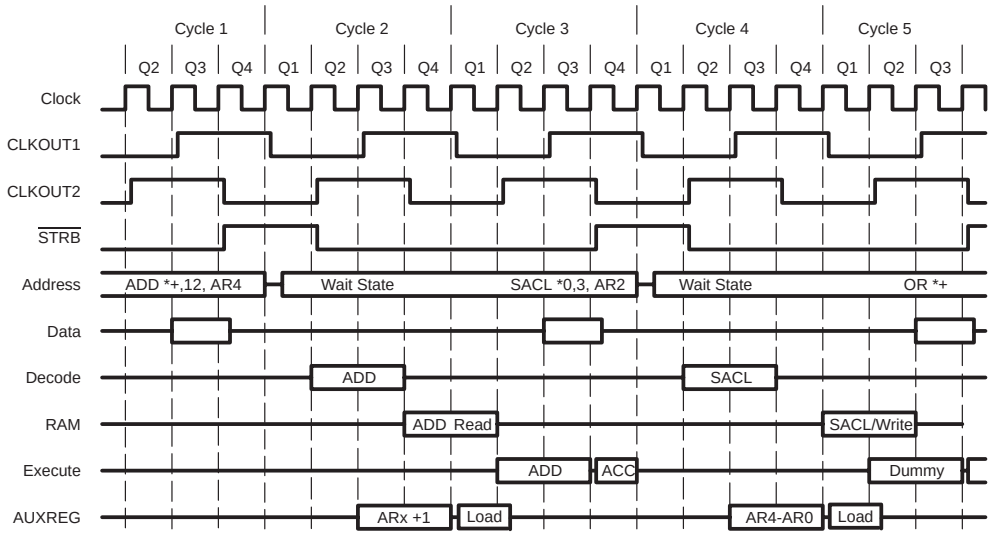


When the device is reading instructions out of on-chip ROM, the basic internal operation of the pipeline is the same. The only difference is that the control lines (that is, $\overline{\text{STRB}}$, $\overline{\text{PS}}$, and R/$\overline{\text{W}}$) are inactive. If the device is fetching the instructions from on-chip RAM, the pipeline is shortened to 2.5 cycles, since the device can fetch the instruction in half a cycle as opposed to the full cycle required in an external or on-chip ROM fetch. The instruction is fetched during Q4 and Q1, then decoded in Q2 and Q3. The rest of the pipeline tracks as described above.

Some operations add additional machine cycles to the instruction execution without damaging the integrity of the program or hardware. External wait states, multiplexed data bus conflicts, two-word instructions, and program counter discontinuities are included in these operations, as described in the following paragraphs.

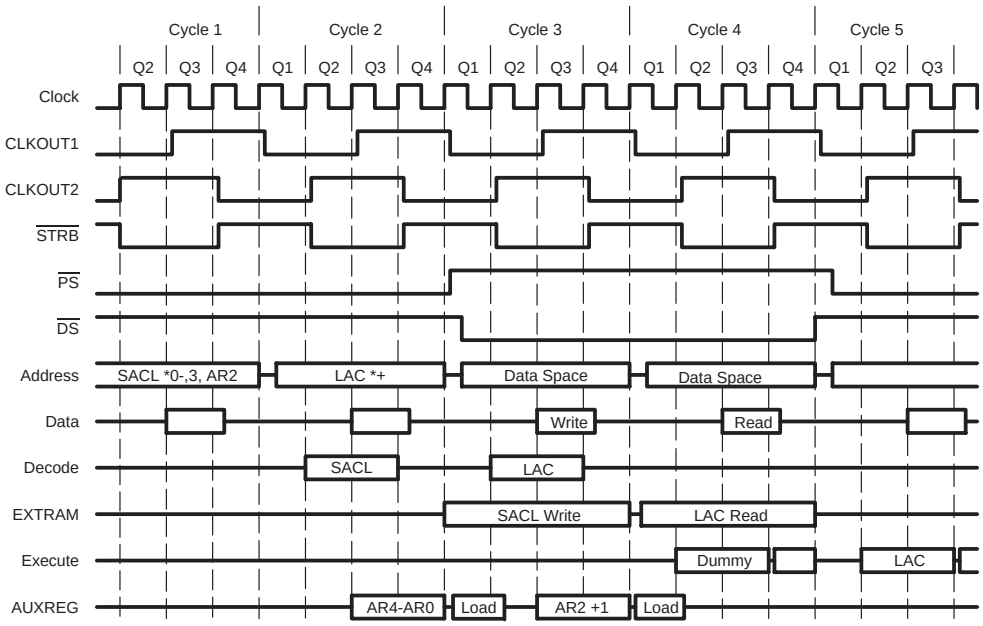
Wait States. The TMS320C25 is designed to be interfaced to slower external devices through the use of hardware-generated wait states. This applies to the program, data, and I/O memory spaces of the Harvard architecture. Wait states are a direct delay on the instruction pipeline. Each wait state inserted during the instruction fetch contributes an additional machine cycle in the pipeline execution of the instruction. In addition, any wait state incurred when accessing external data or I/O space also contributes an additional machine cycle to the pipeline execution of the instruction. This factor applies to all instructions. Figure 3–20 describes how the pipeline reacts to wait states in external program memory. Note that the wait state added in cycle 2 results in a no-execution operation in cycle 4.

Figure 3–20. Pipeline Operation With Wait States



Multiplexed External Data Bus. The external data bus is multiplexed to support all three memory spaces of the TMS320C25. Therefore, external fetches to multiple spaces in the same instruction add additional machine cycles to the pipeline execution of the instruction. This is due to the fact that the external fetch takes a full cycle, whereas the internal equivalent takes two quarter phases and can be included in the execution stage of the three-deep pipeline. Accessing the data memory space is controlled by setting of the data page pointer or the value contained in the auxiliary register used in any instruction. Also affecting the pipeline is the access of the I/O bus or the tables in program memory (that is, IN, OUT, TBLR, and TBLW). Figure 3–21 shows how the pipeline processes an instruction with external program and data access.

Figure 3–21. Pipeline With External Data Bus Conflict



Two-Word Instructions. All two-word instructions take an additional cycle to fetch the 16-bit immediate operand following the instruction mnemonic. The first set of instructions for which this applies is the long immediate instructions. The instruction mnemonic is followed by a 16-bit immediate operand to be executed in the ALU. The second set applies to those instructions that use the PFC register as a second data addressing unit on some optimized instructions—for example, the multiply/accumulate and block move instructions (MAC, MACD, BLKP, and BLKD). In the second set, the extra cycle appears only once in a repeat loop. The third set involves conditional branches not taken.

Program Counter Discontinuities. Because the TMS320C25 is pipelined, a change (other than an increment) in the program counter requires that the pipeline be flushed. This applies to all branches, subroutine calls, software traps, interrupt traps, and returns. The pipeline, being three deep, has the next instruction already loaded when the branch occurs. At this point, this instruction will not affect any data or registers, so it is cleared from the pipeline. Therefore, two dead execution cycles are inserted while waiting for the pipeline to reload. The device takes only one additional cycle if the destination of the branch is in on-chip RAM block 0. The pipeline is only two-deep in this case and takes only one cycle to reload. Figure 3–22 shows a branch from normal execution to an address in on-chip RAM, and Figure 3–23 shows an example of a return executed from on-chip RAM to a location in off-chip memory.

Figure 3–22. Pipeline Operation of Branch to On-Chip RAM

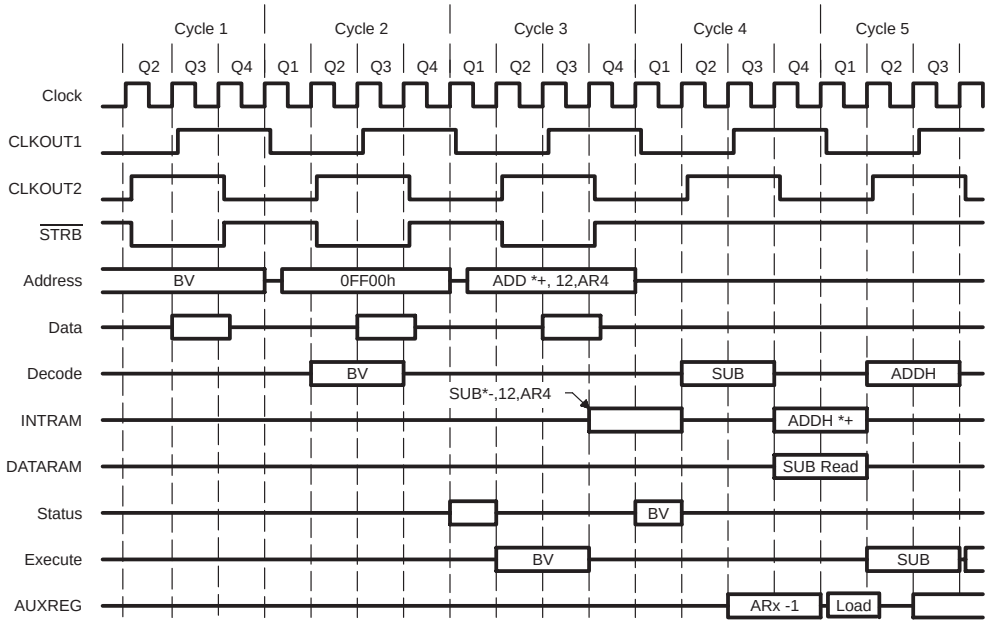
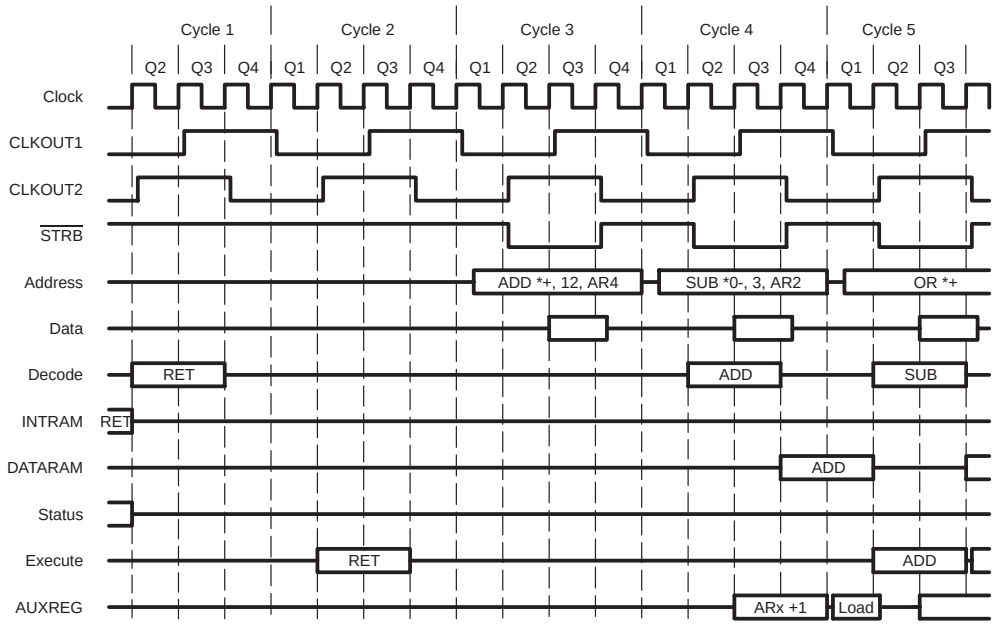


Figure 3–23. Pipeline Operation of RET From On-Chip RAM



Interrupts are hardware-generated discontinuities to the sequential accessing of the program counter. The interrupt is executed based upon instruction execution complete, rather than memory operation complete. The instruction that is currently executing at the time of an interrupt executes completely. The interrupt traps following the completion of that instruction before the start of the execution of the next instruction. In this case, the repeated instruction is considered one execution; therefore, the repeat loop finishes before the interrupt trap is taken. This gives priority to the algorithm over the interrupt service. The interrupt operation in reference to the pipeline execution is illustrated in the data sheet timing diagrams (see Appendix A). Note that when interrupt vectors reside in external memory running with one wait state, there are two interrupt acknowledge ($\overline{\text{IACK}}$) pulses. If this is a problem, the $\overline{\text{IACK}}$ line should be gated with READY.

Hardware Aspects of the Pipeline. Viewing these effects on the pipeline at the hardware level requires additional explanation due to the lack of visibility of on-chip operations or optimization of the pipeline execution. The following paragraphs describe the effects of $\overline{\text{HOLD}}$/$\overline{\text{HOLDA}}$, $\overline{\text{RS}}$, interrupts, accumulator store, on-chip program access, external data access, and repeats as they are visible from the pins of the device. In the cases of $\overline{\text{RS}}$, interrupts, and $\overline{\text{HOLD}}$/$\overline{\text{HOLDA}}$, the effects on the pipeline are shown in the data sheet timing diagrams (see Appendix A).

Reset. The reset interrupt is a totally nonmaskable interrupt. When executed, it stops operation of the pipeline and flushes the unexecuted parts. The reset pulse must be at least three CLKOUT cycles wide. After the second CLKOUT cycle has completed (before the third rising edge of CLKOUT1), the device has brought all outputs into a high-impedance state. After the rising edge of $\overline{RS}$, the device begins to fetch the reset vector. Since the pipeline is empty, it does not execute the reset vector branch until two cycles later. If the $\overline{HOLD}$ line is brought low during the active reset, the device does not start the fetch of the reset vector until after the active $\overline{HOLD}$ is removed and the device deactivates the $\overline{HOLDA}$ line. When $\overline{HOLD}$ is activated with $\overline{RS}$ to allow bootloading of the code, the $\overline{HOLDA}$ line will go active low in three cycles, regardless of whether or not the $\overline{RS}$ line has gone high. This is useful in that the $\overline{HOLDA}$ line can be used to enable the release of the $\overline{RS}$ line and guarantee the required three-cycle reset.

Interrupts. The effects of an interrupt become apparent on the hardware when a interrupt acknowledge ($\overline{IACK}$) signal is valid on the rising edge of CLKOUT2. This signifies the fetch of the first word of the interrupt vector. If wait states are generated in the memory segment where the interrupt vector resides, an additional $\overline{IACK}$ pulse occurs for each wait state added. If this causes a problem with the external interface, $\overline{IACK}$ can be gated with READY to accept only the last interrupt acknowledge pulse. Note that the BIOZ instruction tests the level of the $\overline{BIO}$ pin during the instruction fetch phase of the pipeline.

Hold/Hold Acknowledge.The hold operation, like that of interrupt, takes second priority to algorithm execution; therefore, the hold will not be acknowledged until after the currently running instruction is completed (a minimum of three cycles). This includes repeated instructions. The next instruction, after the final instruction executed before $\overline{HOLDA}$, is latched into the pipeline and executed two cycles after the $\overline{HOLDA}$ line goes inactive high. The second instruction after the last instruction executed is fetched two cycles again after the $\overline{HOLDA}$ line goes inactive high. If the HM bit of status register ST1 is set high, the TMS320C25 stops execution and sits idle until the hold is removed. This lowers power consumption by removing the drive of the memory address and control lines and also stopping major parts of the internal CPU circuits from switching and drawing power. This can be used as a hardware powerdown mode. If the HM bit is low, the TMS320C25 continues executing any instruction that can be executed with on-chip resources only. This means both program and data reside in on-chip memory. The device will continue to operate normally unless an off-chip access is required by an instruction, at which time the processor adds wait states until the hold state is removed. When running from on-chip resources with HM = 0, the processor acknowledges $\overline{HOLD}$ with $\overline{HOLDA}$ during a multicycle instruction.

On-Chip Program Access. When you execute from on-chip resources, the pipeline is visible only in the $\overline{MSC}$ line, which signals microstate complete when active low on the rising edge of CLKOUT2. Note that executing from on-chip program memory does not allow instruction accessing of external data

memory to run in a single cycle. The normal operation of the instruction takes only two quarter phases of the execution cycle to fetch the on-chip data memory, whereas off-chip access requires all four quarter phases. The pipeline is, however, optimized to handle a repeated instruction that accesses external data memory with only one extra cycle for the first external fetch.

External Program/Data Access. Visibility of the pipeline when using external program and data memory requires a monitoring of the $\overline{\text{MSC}}$, $\overline{\text{STRB}}$, $\overline{\text{PS}}$, and $\overline{\text{DS}}$ lines. The $\overline{\text{MSC}}$ line indicates at the rising edge of CLKOUT2 whether or not the cycle is the beginning of a new instruction fetch; that is, $\overline{\text{MSC}}$ active low indicates the completion of an instruction and the acquisition of another instruction. The $\overline{\text{PS}}$ (program select) line indicates that the data bus is currently being used to fetch an instruction. A step in the pipeline is not indicated, since the $\overline{\text{PS}}$ line remains while the pipeline is fetching instructions externally. To track the fetches, the $\overline{\text{STRB}}$ line, which frames external accesses, must be monitored.

The $\overline{\text{PS}}$ line being active low does not necessarily mean that the device is fetching an instruction. In the cases of table read/write (TBLR/TBLW), multiply/accumulate (MAC/MACD), and block transfer (BLKP) instructions, the device uses the $\overline{\text{PS}}$ line active low to access tables.

To monitor external data memory fetches, watch the data select ($\overline{\text{DS}}$) line in conjunction with the $\overline{\text{STRB}}$ line. An active low on the DS line indicates the data bus is currently being used to access data memory space. This line remains low for two memory fetches in the case of an accumulator store followed by an ALU instruction, both operating with off-chip memory. However, two $\overline{\text{STRB}}$ pulses will identify the individual access. Likewise, the line remains low for many cycles in the case of a repeated instruction. I/O space access operates similarily to data space operation with the OUT and IN instructions replacing the save and ALU instruction.

A clear understanding of this information in conjunction with the data in Appendix E should be sufficient to predict the operation of the TMS320C25 pipeline.

3.6.3 Reset

Reset ($\overline{\text{RS}}$) is a nonmaskable external interrupt that can be used at any time to put the TMS320C2x into a known state. Reset is typically applied after powerup when the machine is in a random state.

Driving the $\overline{\text{RS}}$ signal low causes the TMS320C2x to terminate execution and forces the program counter to zero. $\overline{\text{RS}}$ affects various registers and status bits. At powerup, the state of the processor is undefined. For correct system operation after powerup, a reset signal must be asserted low for at least three clock cycles to guarantee a reset of the device (see Section 5.1 for other important reset considerations). Processor execution begins at location 0, which normally contains a B (branch) statement to direct program execution to the system initialization routine (also see Section 5.1 for an initialization routine example). Section 6.1 provides system control circuitry design examples.

When an $\overline{RS}$ signal is received, the following actions take place:

1) RAM configuration bits are set so that all on-chip RAM resides in data space.

2) The program counter (PC) is set to 0, and the address bus A15–A0 is driven with all zeros while $\overline{RS}$ is low.

3) The data bus D15–D0 is placed in the high-impedance state.

4) All memory and I/O space control signals ($\overline{PS}$, $\overline{DS}$, $\overline{IS}$, R/$\overline{W}$, $\overline{STRB}$, and $\overline{BR}$) are deasserted by setting them to high levels while $\overline{RS}$ is low.

5) All interrupts are disabled by setting the INTM (interrupt mode) bit to 1. (Note that $\overline{RS}$ is nonmaskable.) The interrupt flag register (IFR) is reset to all zeros.

6) Status bits are set:
For all TMS320C2x devices, $0 \rightarrow$ OV, $1 \rightarrow$ XF, $0 \rightarrow$ FO, $0 \rightarrow$ TXM, $0 \rightarrow$ CNF ($0 \rightarrow$ CNF0, $0 \rightarrow$ CNF1 for the TMS320C26), $1 \rightarrow$ SXM, $0 \rightarrow$ PM, $1 \rightarrow$ HM, $1 \rightarrow$ C, and $1 \rightarrow$ FSM. The remaining status bits on the TMS320C2x are unchanged.

7) The global memory allocation register (GREG) is cleared to make all memory local.

8) The RPTC (repeat counter) is cleared.

9) The DX (data transmit) pin is placed in the high-impedance state. Any transmit/receive operations on the serial port are terminated, and the TXM (transmit mode) bit is reset to a low level. This configures the FSX framing pulse to be an input. A transmit/receive operation may be started by framing pulses only after the removal of $\overline{RS}$.

10) The TIM register is set to the maximum value (0FFFFh) on reset. Also, the PRD register on the TMS320C25 is initialized by reset to 0FFFFh. (See Example 5–1). The TIM register begins decrementing only after RS is deasserted.

11) The $\overline{IACK}$ (interrupt acknowledge) signal is generated in the same manner as a maskable interrupt.

12) The state of the RAM is undefined following $\overline{RS}$.

13) The ARB, ARP, DP, IMR, OVM, and TC bits are not initialized by reset. Therefore, it is critical that you initialize these bits in software following reset.

Execution starts from location 0 of program memory when the $\overline{RS}$ signal is taken high. Note that if $\overline{RS}$ is asserted while in the hold mode, normal reset operation occurs internally, but all buses and control lines remain in the high-impedance state. Upon release of HOLD and $\overline{RS}$, execution starts from location zero. The TMS320C2x can be held in the reset state indefinitely.

Note:

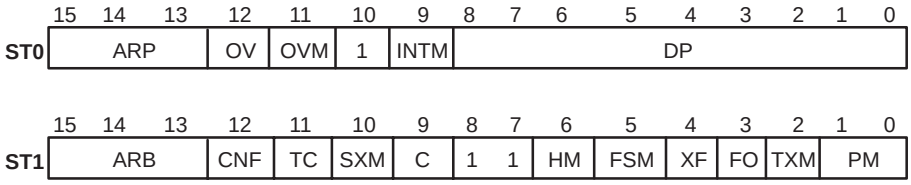
Reset does not have internal Schmidt hysteresis. To insure proper reset operation, avoid slow rise and fall times.

3.6.4 Status Registers

Two status registers, ST0 and ST1, contain the status of various conditions and modes. The status registers can be stored into data memory and loaded from data memory, thus allowing the status of the machine to be saved and restored for interrupts and subroutines. All status bits are written to and read from using LST/LST1 and SST/SST1 instructions, respectively (with the exception of INTM, which cannot be loaded via an LST instruction).

Figure 3–24 shows the organization of both status registers, indicating all status bits contained in each. Note that the DP, ARP, and ARB registers are shown as separate registers in the processor block diagram of Figure 3–2. Because these registers do not have separate instructions for storing them into RAM, they are included in the status registers. As shown in Figure 3–24, several bits in the status registers are reserved and read as logic 1s by the LST and LST1 instructions.

Figure 3–24. TMS320C2x Status Register Organization



The status register ST1 of the TMS320C26 uses one of the unused bits and the CNF bit of the TMS320C25 to define the four configuration modes as described above. The bits are named CNF0 and CNF1 and can be set by the instruction CONF *const*, where *const* is a number between 0 and 3. This two-bit constant is loaded into the two status register bits CNF0 and CNF1.

Some additional instructions or functions may affect the status bits, as indicated in Table 3–6.

The bits can also be modified by the LST1 instruction, and both are set to 0 by RESET. If TMS320C26 designs are started by using the TMS320C25 as a base, consider defining the mask for loading the status register ST1 with the instruction LST1 in such a way that the TMS320C26 is also configured as desired.

Figure 3–25 shows the two status registers of the TMS320C26. All bits, besides the redefined CNF0 (CNF in the TMS320C25) and the new CNF1 bit, are unchanged.

Figure 3–25. TMS320C26 Status Register Organization

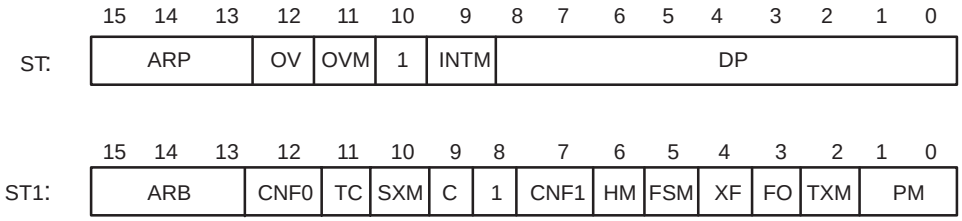


Table 3–6. Status Register Field Definitions

Field	Function
ARB	Auxiliary register pointer buffer. Whenever the ARP is loaded, the old ARP value is copied to the ARB except during an LST instruction. When the ARB is loaded via an LST1 instruction, the same value is also copied to the ARP.
ARP	Auxiliary register pointer. This three-bit field selects the AR to be used in indirect addressing. When ARP is loaded, the old ARP value is copied to the ARB register. ARP may be modified by memory-reference instructions when using indirect addressing, and by the LARP, MAR, and LST instructions. ARP is also loaded with the same value as ARB when an LST1 instruction is executed.
C	Carry bit. This bit is set to 1 if the result of an addition generates a carry, or reset to 0 if the result of a subtraction generates a borrow. Otherwise, it is reset after an addition or set after a subtraction, except if the instruction is ADDH or SUBH. ADDH can only set and SUBH only reset the carry bit, but cannot affect it otherwise. These instructions will also affect this bit: SC, RC, LST1, shift, and rotate. Two branch instructions, BC and BNC, have been provided to branch on the status of C. C is set to 1 on a reset.
CNF	On-chip ram configuration control bit. If set to 0, block B0 is configured as data memory; otherwise, block B0 is configured as program memory. The CNF may be modified by the CNFD, CNFP, and LST1 instructions. $\overline{RS}$ resets the CNF to 0.
DP	Data memory page pointer. The 9-bit DP register is concatenated with the 7 LSBs of an instruction word to form a direct memory address of 16 bits. DP may be modified by the LST, LDP, and LDPK instructions.
CNF*X*	*X* = 0 or 1: CNF0 and CNF1 are the on-chip RAM configuration control bits for the TMS320C26. Depending on the status of these 2 bits, one of the 4 configuration modes can be selected. $\overline{RS}$ resets both CNF0 and CNF1 to 0.
FO	Format bit. When set to 0, the serial port registers are configured as 16-bit registers. When set to 1, the port registers are configured to receive and transmit eight-bit bytes. FO may be modified by the FORT and LST1 instructions. FO is reset to 0.
FSM	Frame synchronization mode bit. This bit indicates whether the serial port operates with or without frame sync pulses. When FSM = 1, the serial port operation is initiated following a frame sync pulse on the FSX/FSR inputs. When FSM = 0, the FSX/FSR inputs are ignored and the serial port operates continuously with no frame sync pulses required. The bit is set to 1 by a reset.

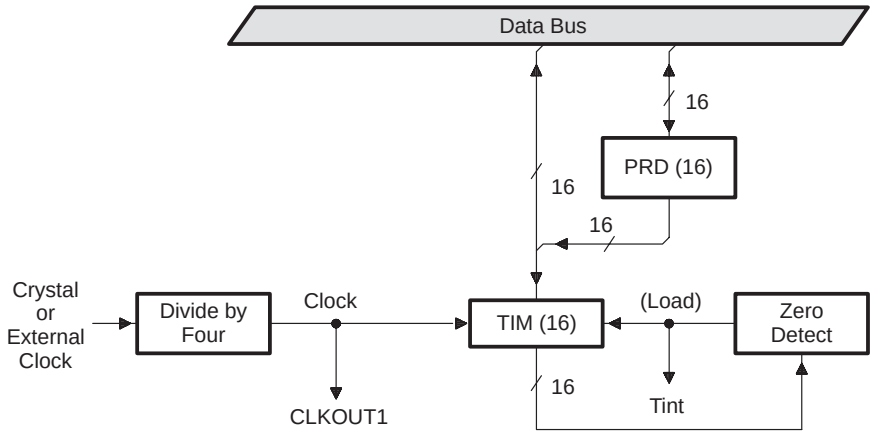
Table 3–6. Status Register Field Definitions (Continued)

Field	Function
HM	Hold mode bit. When HM = 1, the processor halts internal execution when acknowledging an active HOLD. When HM = 0, the processor may continue execution out of internal program memory but puts its external interface in a high-impedance state. This bit is set to 1 by a reset.
INTM	Interrupt mode bit. When set to 0, all unmasked interrupts are enabled. When set to 1, all maskable interrupts are disabled. INTM is set and reset by the DINT and EINT instructions. RS and IACK also set INTM. INTM has no effect on the unmaskable RS interrupt. Note that INTM is unaffected by the LST instruction.
OV	Overflow flag bit. As a latched overflow signal, OV is set to 1 when overflow occurs in the ALU. Once an overflow occurs, the OV remains set until a reset, BV, BNV, or LST instruction clears the OV.
OVM	Overflow mode bit. When set to 0, overflowed results overflow normally in the accumulator. When set to 1, the accumulator is set to either its most positive or its most negative value upon encountering an overflow. The SOVM and ROVM instructions set and reset this bit, respectively. LST may also be used to modify the OVM.
PM	Product shift mode. If these two bits are 00, the multiplier's 32-bit product is loaded into the ALU with no shift. If PM = 01, the PR output is left-shifted one place and loaded into the ALU, with the LSBs zero-filled. If PM = 10, the PR output is left-shifted by four bits and loaded into the ALU, with the LSBs zero-filled. PM = 11 produces a right shift of six bits, sign-extended. Note that the PR contents remain unchanged. The shift takes place when transferring the contents of the PR to the ALU. PM is loaded by the SPM and LST1 instructions. The PM bits are cleared by RS.
SXM	Sign-extension mode bit. SXM = 1 produces sign extension on data as it is passed into the accumulator through the scaling shifter. SXM = 0 suppresses sign extension. SXM does not affect the definition of certain instructions; for example, the ADDS instruction suppresses sign extension regardless of SXM. This bit is set and reset by the SSXM and RSXM instructions, and may also be loaded by LST1. SXM is set to 1 by RS.
TC	Test/control flag bit. The TC bit is affected by the BIT, BITT, CMPR, LST1, and NORM instructions. The TC bit is set to a 1 if a bit tested by BIT or BITT is a 1, if a compare condition tested by CMPR exists between AR0 and another AR pointed to by ARP, or if the exclusive-OR function of the two MSBs of the accumulator is true when tested by a NORM instruction. Two branch instructions, BBZ and BBNZ, provide branching on the status of the TC.
TXM	Transmit mode bit. TXM = 1 configures the serial port's FSX pin to be an output. In this mode, a pulse is produced on FSX when DXR is loaded. Transmission then starts on the DX pin. TXM = 0 configures the FSX pin to be an input. TXM is set and reset by the STXM and RTXM instructions and may also be loaded by LST1. RS resets TXM to 0.
XF	XF pin status bit. This status bit indicates the state of the XF pin, a general-purpose output pin. XF is set and reset by the SXF and RXF instructions or may be loaded by LST1. XF is set to 1 by RS.

3.6.5 Timer Operation

The TMS320C2x provides a memory-mapped 16-bit timer (TIM) register and a 16-bit period (PRD) register, as shown in Figure 3–26. The on-chip timer is a down counter that is continuously clocked by CLKOUT1.

Figure 3–26. Timer Block Diagram



The TIM register is set to the maximum value (0FFFFh) on reset for the TMS320C25. The PRD register on the TMS320C25 is also initialized by reset to 0FFFFh. (See Example 5–1). The TIM register begins decrementing only after $\overline{RS}$ is deasserted. Following this, the TIM and PRD registers may be reloaded under program control. See subsection 3.6.3 for reset information.

The TIM register, data memory location 2, holds the current count of the timer. At every CLKOUT1 cycle the TIM register is decremented by one. The PRD register, data memory location 3, holds the starting count for the timer. A timer interrupt (TINT) is generated every time the timer decrements to zero. The timer is reloaded with the value contained in the period (PRD) register within the next cycle after it reaches zero so that interrupts can be programmed to occur at regular intervals of (PRD + 1) cycles of CLKOUT1. This feature is useful for control operations and for synchronously sampling or writing to peripherals. By programming the PRD register from 1 to 65,535 (0FFFFh), a TINT can be generated every 2 to 65,536 cycles on the TMS320C25. A PRD register value of zero is not allowed.

The timer and period registers can be read from or written to on any cycle. The count can be monitored by reading the TIM register. A new counter period can be written to the period register without disturbing the current timer count. The timer will then start the new period after the current count is complete. If both the PRD and TIM registers are loaded with a new period, the timer begins decrementing the new period without generating an interrupt. Thus, the programmer has complete control of the current and next periods of the timer.

If the timer is not used, either TINT is to be masked or all maskable interrupts are to be disabled by a DINT instruction. The PRD register can then be used as a general-purpose data memory location. If TINT is used, the PRD and TIM registers are to be programmed before unmasking the TINT.

3.6.6 Repeat Counter

The repeat counter (RPTC) is an 8-bit counter, which, when loaded with a number N, causes the next single instruction to be executed N + 1 times. The RPTC can be loaded with a number from 0 to 255 using either the RPT (repeat) or RPTK (repeat immediate) instructions. This results in a maximum of 256 executions of a given instruction. RPTC is cleared by reset.

The repeat feature can be used with instructions such as multiply/accumulates (MAC/MACD), block moves (BLKD/BLKP), I/O transfers (IN/OUT), and table read/writes (TBLR/TBLW). These instructions, which are normally multicycle, are pipelined when using the repeat feature, and effectively become single-cycle instructions. For example, the table read instruction may take three or more cycles to execute, but when repeated, a table location can be read every cycle. Note that not all instructions can be repeated (see Section 4.3 and Appendix E for more information).

3.6.7 Powerdown Modes (TMS320C25)

When operated in either of two powerdown modes, the TMS320C25 enters a dormant state and requires approximately one-half the power normally needed to supply the device (see the data sheet, Appendix A). Depending upon the application, one powerdown mode is invoked by executing an IDLE instruction while the other mode is invoked by driving the $\overline{\text{HOLD}}$ input low while the HM status bit is set to one.

While in a powerdown condition, all of the internal contents of the TMS320C25 are retained. This allows the operation to continue unaltered after the powerdown condition is terminated. If the powerdown mode was entered by driving $\overline{\text{HOLD}}$ low with HM = 1, the data and address buses and the interface control signals ($\overline{\text{PS}}$, $\overline{\text{DS}}$, $\overline{\text{IS}}$, $\overline{\text{STRB}}$, and R/$\overline{\text{W}}$) are all maintained in the high-impedance state. If the mode was entered by the IDLE instruction, only the data bus goes to the high-impedance state; address bus and interface control signals are maintained in a steady-state condition and can still be driven. In accordance with the execution process, the powerdown mode may be terminated either by removing the $\overline{\text{HOLD}}$ input or by applying an interrupt signal during the IDLE operation. For application and other information, refer to the descriptions of the IDLE instruction in Chapter 4 and the hold function in subsection 3.10.3.

3.7 External Memory and I/O Interface

The TMS320C2x supports a wide range of system interfacing requirements. Data, program, and I/O address spaces provide interfacing to memory and I/O, thus maximizing system throughput. The local memory interface consists of:

- A 16-bit parallel data bus (D15–D0),
- A 16-bit address bus (A15–A0),
- Data, program, and I/O space select ($\overline{DS}$, $\overline{PS}$, and $\overline{IS}$) signals, and
- Various system control signals.

The R/$\overline{W}$ (read/write) signal controls the direction of the transfer, and $\overline{STRB}$ (strobe) provides a timing signal to control the transfer.

The TMS320C2x I/O space consists of 16 input and 16 output ports. These ports provide the full 16-bit parallel I/O interface via the data bus on the device. A single input or output operation, using the IN or OUT instructions, typically takes two cycles; however, when used with the repeat counter, the operation becomes single-cycle.

I/O design is simplified by having I/O treated the same way as memory. I/O devices are mapped into the I/O address space using the processor's external address and data buses in the same manner as memory-mapped devices. When addressing internal memory, the data bus must be in the high-impedance state and the control signals go to an inactive state (logic high). Refer to Chapter 5 for the effect instructions have on I/O.

Interfacing to memory and I/O devices of varying speeds is accomplished by using the READY line. When communicating with slower devices, the TMS320C2x processor waits until the other device completes its function, signals the processor via the READY line, and continues execution (see Chapter 6).

3.7.1 Memory Combinations

The exact sequence of operations performed as instructions execute depends on the areas in memory where the instructions and operands are located. There are eight possible combinations of program and data memory because information can be located in internal RAM, external memory, or internal ROM/EPROM (available on TMS320C25 /TMS320E25). The eight possible combinations are:

1) Program Internal RAM/Data Internal (PI/DI)

2) Program Internal RAM/Data External (PI/DE)

3) Program External/Data Internal (PE/DI)

4) Program External/Data External (PE/DE)

5) Program Internal ROM/Data Internal (PR/DI) on the TMS320C25

6) Program Internal EPROM/Data Internal (PR/DI) on the TMS320E25

7) Program Internal ROM/Data External (PR/DE) on the TMS320C25

8) Program Internal EPROM/Data External (PR/DE) on the TMS320E25

Appendix E provides cycle timings for instructions, both when repeated and when not repeated. The following is a summary of program execution, organized according to memory configuration.

PI/DI or PR/DI When both program and data memory are on-chip, the processor runs at full speed with no wait states. Note that IN and OUT instructions have different cycle timings when program memory is internal; IN requires two cycles to execute, whereas OUT requires only one cycle.

PE/DI If external program memory is sufficiently fast, this memory mode can run at full speed because internal data operations can occur coincidentally with external program memory accesses. If external program memory is not fast enough, wait states may be generated by using the READY input.

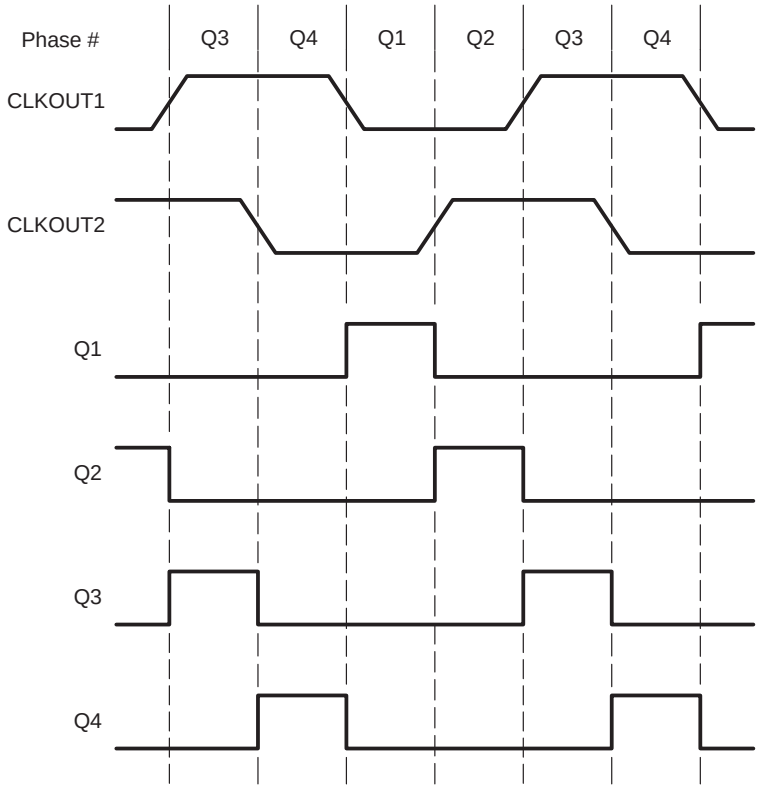
PI/DE, PE/DE, or PR/DE
Additional cycles are required to execute instructions that reference an external data memory space. At least two cycles are required to execute *read from external data memory* instructions such as ADD, LAR, etc. Further additional cycles may be required because of wait states if external data memory is not fast enough to be accessed within a single cycle. Note, however, that the TMS320C2x has the capability of executing *write to external data memory* instructions in a single cycle when program memory is internal (two cycles are required if program memory is also external). Additional cycles are also required in this case if external data memory is not sufficiently fast.

In all memory configurations where the same bus is used to communicate with external data, program, or I/O space, the number of cycles required to execute a particular instruction may further vary, depending on whether the next instruction fetch is from internal or external program memory. Instruction execution and operation of the pipeline are discussed in subsection 3.6.2 and in the succeeding subsections.

3.7.2 Internal Clock Timing Relationships

The crystal or external clock source frequency is divided to produce an internal four-phase clock. The four phases are defined by CLKOUT1 and CLKOUT2, as shown in Figure 3–27.

Figure 3–27. Four-Phase Clock



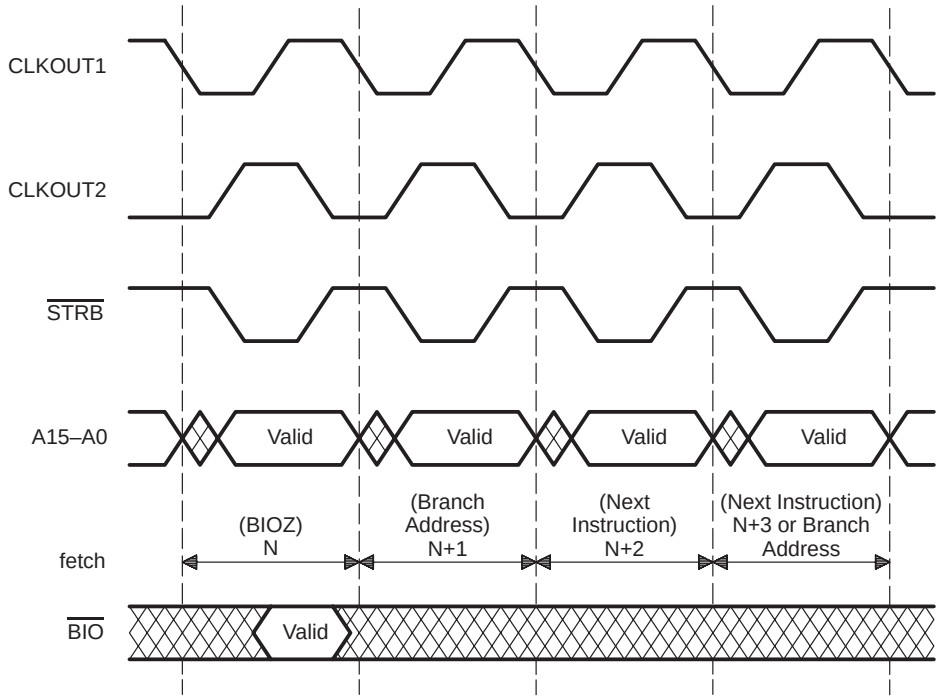
3.7.3 General-Purpose I/O Pins ($\overline{\text{BIO}}$ and XF)

The TMS320C2x has two general-purpose pins that are software-controlled. The $\overline{\text{BIO}}$ pin is a branch control input pin, and the XF pin is an external flag output pin.

The $\overline{\text{BIO}}$ pin is useful for monitoring peripheral device status. It is especially useful as an alternative to using an interrupt when it is necessary not to disturb time-critical loops. When the $\overline{\text{BIO}}$ input pin is active (low), execution of the BIOZ instruction causes a branch to occur.

In Figure 3–28, $\overline{\text{BIO}}$ is sampled at the end of Q4. The timing diagram shown is for a sequence of single-cycle, single-word instructions without branches located in external memory. Because of variations in pipelining due to instructions prior to and following the BIOZ instruction, this timing may vary. Therefore, it is recommended that several cycles of setup be provided if $\overline{\text{BIO}}$ is to be recognized on a particular cycle.

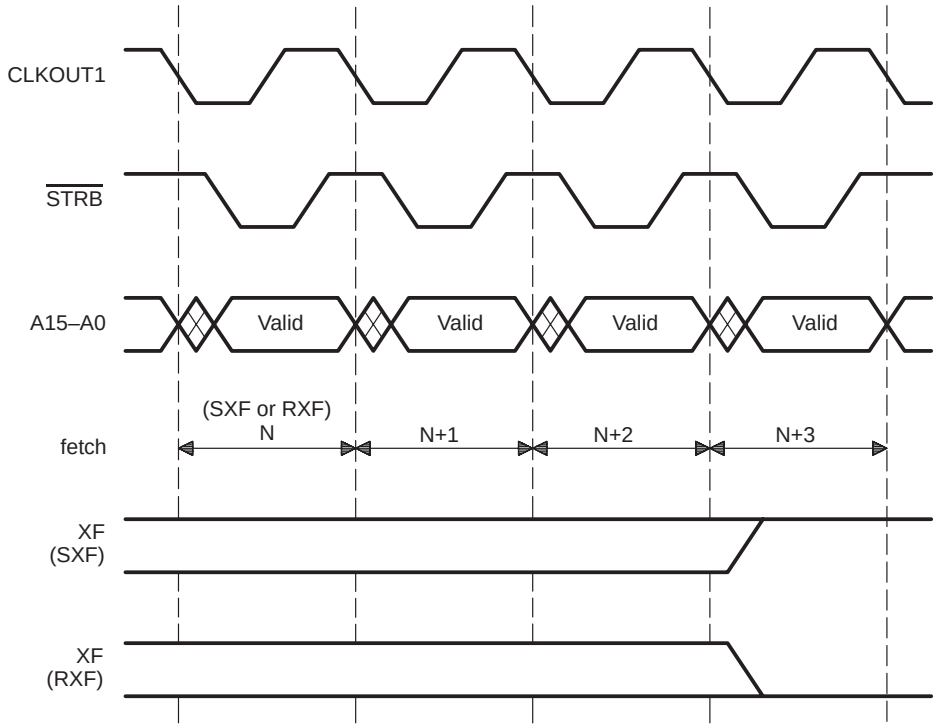
Figure 3–28. $\overline{\text{BIO}}$ Timing Diagram



The XF (external flag) output pin is set to a high level by the SXF (set external flag) instruction and reset to a low level by the RXF (reset external flag) instruction. XF is set high by $\overline{\text{RS}}$.

The relationship between the time the SXF/RXF instruction is fetched before the XF pin is set or reset is shown in Figure 3–29. As with $\overline{\text{BIO}}$, the timing shown for XF is for a sequence of single-cycle, single-word instructions located in external memory. Actual timing may vary with different instruction sequences.

Figure 3–29. External Flag Timing Diagram



Notes: 1) N is the program memory location for the current instruction.
2) This example shows only the execution of single-cycle instructions fetched from external program memory.

3.8 Interrupts

The TMS320C2x has three external maskable user interrupts ($\overline{INT}$2–$\overline{INT}$0), available for external devices that interrupt the processor. Internal interrupts are generated by the serial port (RINT and XINT), by the timer (TINT), and by the software interrupt (TRAP) instruction. Interrupts are prioritized with reset ($\overline{RS}$) having the highest priority and the serial port transmit interrupt (XINT) having the lowest priority.

3.8.1 Interrupt Operation

This subsection explains details interrupt organization and management. Vector locations and priorities for all internal and external interrupts are shown in Table 3–7. The TRAP instruction, used for software interrupts, is not prioritized but is included here because it has its own vector location. Each interrupt address has been spaced apart by two locations so that branch instructions can be accommodated in those locations if desired.

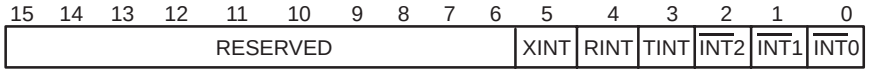
Table 3–7. Interrupt Locations and Priorities

Interrupt Name	Memory Location	Priority	Function
$\overline{RS}$	0h	1 (highest)	External reset signal
$\overline{INT}$0	1h	2	External user interrupt #0
$\overline{INT}$1	2h	3	External user interrupt #1
$\overline{INT}$2	3h	4	External user interrupt #2
	8–17h		Reserved locations
TINT	18h	5	Internal timer interrupt
RINT	1Ah	6	Serial port receive interrupt
XINT	1Ch	7 (lowest)	Serial port transmit interrupt
TRAP	1Eh	N/A	TRAP instruction address

When an interrupt occurs, it is stored in the 6-bit interrupt flag register (IFR). This register is set by the external user interrupts $\overline{INT}$(2–0) and the internal interrupts RINT, XINT, and TINT. Each interrupt is stored in the IFR until it is recognized, and then automatically cleared by the $\overline{IACK}$ (interrupt acknowledge) signal or the $\overline{RS}$ (reset) signal. The $\overline{RS}$ signal is not stored in the IFR. No instructions are provided for reading from or writing to the IFR.

The TMS320C2x has a memory-mapped interrupt mask register (IMR) for masking external and internal interrupts. The layout of the register is shown in Figure 3–30. A 1 in bit positions 5 through 0 of the IMR enables the corresponding interrupt, provided that INTM = 0. The IMR is accessible with both read and write operations but cannot be read using BLKD. When the IMR is read, the unused bits (15 through 6) are read as 1s. The lower six bits are used to write to or read from the IMR. Note that $\overline{RS}$ is not included in the IMR, and therefore the IMR has no effect on reset.

Figure 3–30. Interrupt Mask Register (IMR)



The INTM (interrupt mode) bit, which is bit 9 of status register ST0, enables or disables all maskable interrupts. INTM = 0 enables all the unmasked interrupts, and INTM = 1 disables these interrupts. The INTM is set to 1 by the IACK (interrupt acknowledge) signal, the DINT instruction, or a reset. This bit is reset to 0 by the EINT instruction. Note that the INTM does not actually modify the IMR or IFR.

The TMS320C2x has a built-in mechanism for protecting multicycle instructions from interrupts. If an interrupt occurs during a multicycle instruction, the interrupt is not processed until the instruction is completed. This mechanism also applies to instructions that become multicycle due to the READY signal.

In addition, the device does not allow interrupts to be processed when an instruction is being repeated via the RPT or RPTK instructions. The interrupt is stored in the IFR until the repeat counter (RPTC) decrements to zero, and then the interrupt is processed. Even if the interrupt is not used while the TMS320C2x is processing the RPT or RPTK, the interrupt will still be latched by IFR and pending until RPTC decrements to zero.

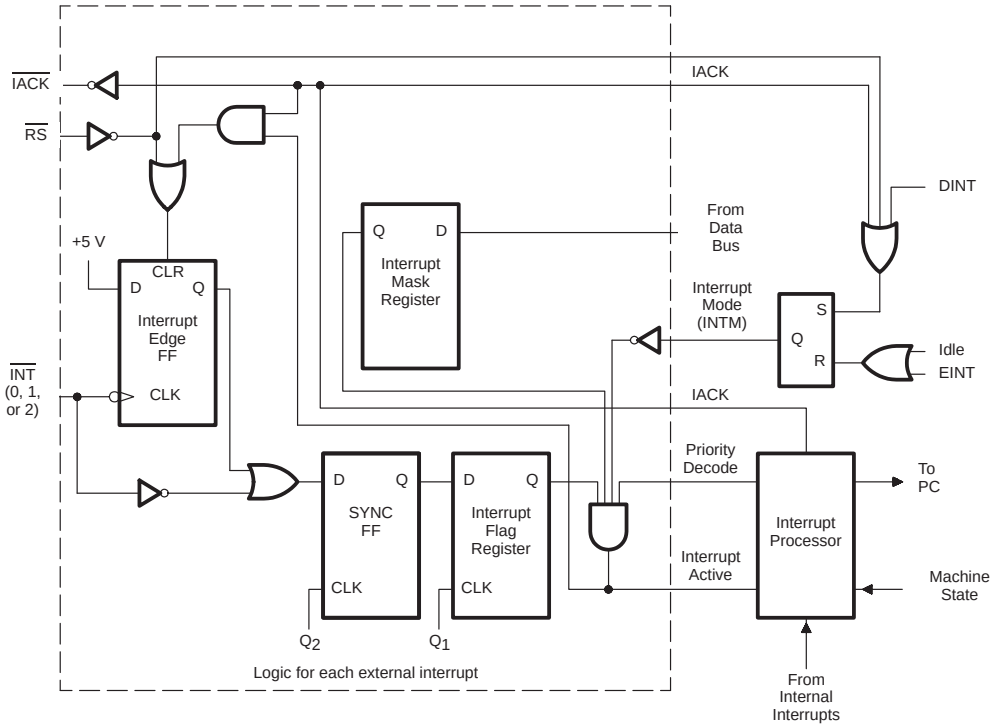
If both the HOLD line and an interrupt go active during a multicycle instruction or a repeat loop, the HOLD takes control of the processor at the end of the instruction or loop. When HOLD is released, the interrupt is acknowledged.

Interrupts cannot be processed between EINT and the next instruction in a program sequence. For example, if an interrupt occurs during an EINT instruction execution, the device always completes EINT as well as the following instruction before the pending interrupt is processed. This insures that a RET can be executed before the next interrupt is processed, assuming that a RET instruction follows the EINT. The state of the machine, upon receiving an interrupt, may be saved and restored (see subsection 5.3.1).

3.8.2 External Interrupt Interface

Interrupts may be asynchronously edge- or level-triggered. In the functional logic organization for INT(2–0), shown in Figure 3–31, the external interrupt INT0 is connected to an edge-triggered flip-flop. The INT0 signal is ORed with the interrupt edge flip-flop Q output and synchronized with internal quarter-phases 1 and 2 to produce an interrupt signal. In this way, the device can handle both edge-triggered and level-triggered interrupts.

Figure 3–31. Internal Interrupt Logic Diagram



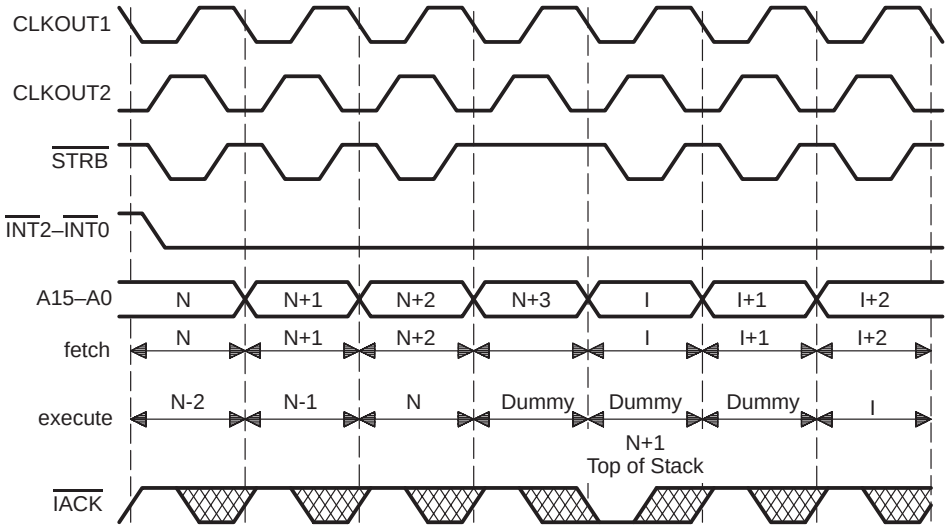
Due to the level sensitivity of the external interrupts and the synchronization of the interrupts (first on Q2, then on Q1 of the following machine cycle), the $\overline{\text{INT}}$ line *must be* set to an inactive high at least two cycles before the enabling interrupts (EINT). If this criteria is not met, the TMS320C25 will immediately take the interrupt trap following the EINT plus the next instruction.

If the INTM bit and mask register have been properly enabled, the interrupt signal is accepted by the processor. An $\overline{\text{IACK}}$ (interrupt acknowledge) signal is then generated. The $\overline{\text{IACK}}$ clears the appropriate interrupt edge flip-flop and disables the INTM latch. The logic is the same for $\overline{\text{INT}}$1 and $\overline{\text{INT}}$2.

In a typical interrupt ($\overline{\text{INT}}$2–$\overline{\text{INT}}$0) operation, the interrupt is generated by a negative-going edge, and the IFR bit is set. Because INTM is disabled when the interrupt is acknowledged, the level may continue to be present on the $\overline{\text{INT}}$ input without generating further interrupts. If the level is removed before an EINT instruction is executed, no further interrupts are generated. If a low level continues to be present after the EINT, another interrupt is generated after the EINT/next instruction sequence. In addition, if the $\overline{\text{INT}}$ pin is pulsed between the previous $\overline{\text{IACK}}$ and EINT, another interrupt is generated after EINT/RET because the corresponding IFR bit is again set.

Figure 3–32 shows an interrupt, interrupt acknowledge, and various other signals for the special case of single-cycle instructions. An interrupt generated during the current (N) fetch cycle still allows the fetch and execution of that instruction. The N+1 and N+2 instructions are also fetched, then discarded, and the address N+1 is pushed onto the top of the stack. The instruction is fetched again upon a return command from the interrupt routine.

Figure 3–32. Interrupt Timing Diagram (TMS320C25)



Notes: 1) N is the program memory location for the current instruction.

2) I is the interrupt vector location in program memory for the active interrupt.

3) For simplicity, this example shows only the execution of single-cycle instructions fetched from external program memory, rather than multicycle instructions.

Three dummy execute cycles occur on an interrupt, as shown in the timing diagram for the TMS320C25 (Figure 3–32). The $\overline{\text{IACK}}$ signal is asserted low during CLKOUT1 low when the device initiates a fetch from the interrupt location I. Note that $\overline{\text{IACK}}$ is a valid signal only when CLKOUT1 is low. An external device can determine which interrupt had occurred by latching the address bus value present on A4–A1 with the rising edge of CLKOUT2 when $\overline{\text{IACK}}$ is low.

3.9 Serial Port

A full-duplex on-chip serial port provides direct communication with serial devices such as codecs, serial A/D converters, and other serial systems. The interface signals are compatible with codecs and many other serial devices with a minimum of external hardware. The serial port may also be used for intercommunication between processors in multiprocessing applications.

Both receive and transmit operations are double-buffered on the TMS320C2x, thus allowing a continuous bit stream even if FSX is an output. The use of the frame sync mode (FSM) bit provides continuous operation that, once initiated, requires no further frame synchronization pulses. No minimum CLKR/CLKX frequency (f_{min} = 0 Hz) is required for serial port operation.

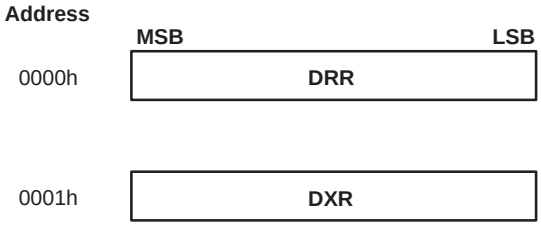
The bits, pins, and registers that control serial port operation are listed in Table 3–8. Availability of a function on a particular device is also indicated.

Table 3–8. Serial Port Bits, Pins, and Registers

Serial Port Bits/Pins/Registers		TMS320C25
FO	Format bit	Yes
TXM	Transmit mode bit	Yes
FSM	Frame synchronization mode bit	Yes
CLKX	Transmit clock signal	Yes
CLKR	Receive clock signal	Yes
DX	Transmitted serial data signal	Yes
DR	Received serial data signal	Yes
FSX	Transmit framing synchronization signal	Yes
FSR	Receive framing synchronization signal	Yes
DXR	Data transmit register	Yes
DRR	Data receive register	Yes
XSR	Transmit shift register	Yes
RSR	Receive shift register	Yes

The serial port uses two memory-mapped registers: the data transmit register (DXR) that holds the data to be transmitted by the serial port, and the data receive register (DRR) that holds the received data (see Figure 3–33). Both registers operate in either the 8-bit byte mode or 16-bit word mode, and may be accessed in the same manner as any other data memory location. Each register has an external clock, a framing synchronization pulse, and associated shift registers. Any instruction accessing data memory can be used to read from or write to these registers; however, the BLKD (block move from data memory to data memory) instruction cannot be used to read these registers. The DXR and DRR registers are mapped into locations 0 and 1 in the data address space. The XSR and RSR registers are not directly accessible through software.

Figure 3–33. The DRR and DXR Registers



If the serial port is not being used, the DXR and DRR registers can be used as general-purpose registers. In this case, the CLKR or FSR should be connected to a logic low to prevent a possible receive operation from being initiated.

Three bits in status register ST1 are used to control the serial port operation: FO, TXM, and FSM. The FO (format) bit defines whether data to be transmitted and received is an 8-bit byte or a 16-bit word. If FO = 0, the data is formatted in 16-bit words. If FO = 1, the data is formatted in 8-bit bytes. In the 8-bit mode, only the eight least significant bits are used for transmit/receive operations. The FO bit is loaded by the FORT (format serial port registers) instruction. On reset, FO is set to 0.

The TXM (transmit mode) bit is used to determine if the frame synchronization pulse for the transmit operation is generated externally or internally. If TXM = 1, the FSX pin becomes an output pin, and a framing pulse is produced on the FSX pin every time the DXR register is loaded. This framing pulse is synchronized with the rising edge of CLKX. If TXM = 0, the FSX pin becomes an input pin. The TMS320C2x then waits for an external synchronization pulse before beginning transmission. On a reset, TXM is set to zero, configuring FSX to be an input. The TXM bit can be loaded by the LST1, STXM, or RTXM instructions.

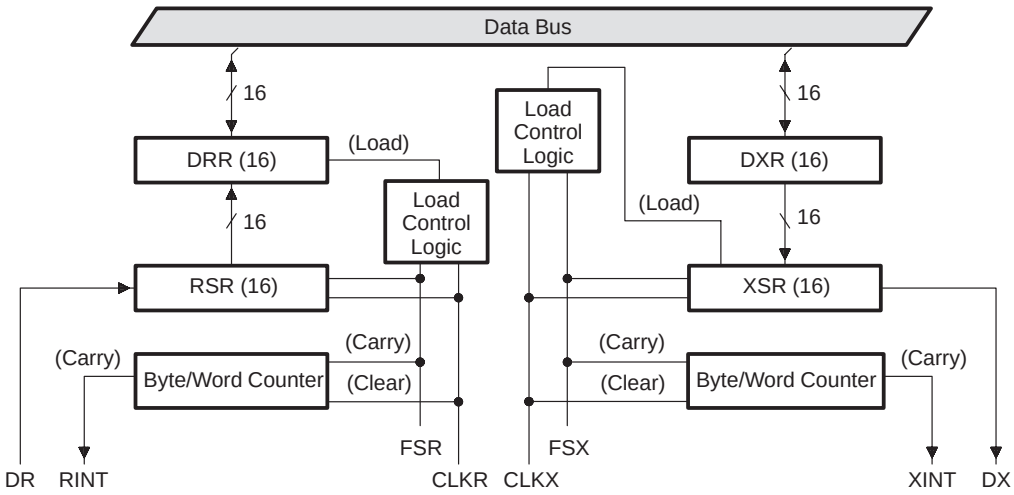
The FSM (frame synchronization mode) status register bit is used to determine whether frame sync pulses are required for each serial port transfer. When FSM = 1, frame sync pulses are required; consequently, they are not required when FSM = 0. FSM is set by the SFSM (set frame synchronization mode) instruction and cleared by the RFSM (reset frame synchronization mode) instruction. When FSM = 1 and frame sync pulses are required, an FSX pulse will cause the XSR to be loaded with data from the DXR, and transmission will begin. If an FSX is presented prior to the last bit of the current transmission, the XSR will be reloaded from the DXR, thus aborting the current transmission and immediately beginning a new one.

The frame sync mode is useful in communicating to PCM highways. For ATT T1 and CCITT G711/712 lines, the processor can communicate directly in these formats by counting the transmitted/received bytes in software and performing SFSM/RFSM instructions as needed to set/reset the FSM bit.

3.9.1 Transmit and Receive Operations

The transmit and receive sections of the serial port are implemented separately to allow independent transmit and receive operations. Externally, the serial port interface is implemented using the six serial port pins. Figure 3–34 shows the registers and pins used in transmit and receive operations.

Figure 3–34. Serial Port Block Diagram



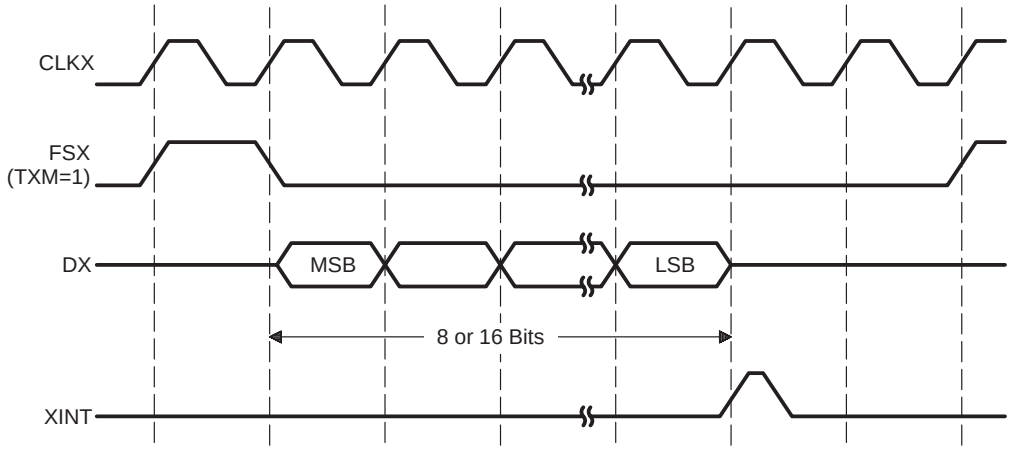
Data is clocked onto the DX pin from the XSR of the TMS320C25 by a CLKX signal. Data is clocked into the RSR of the TMS320C25 from the DR pin by a CLKR signal. CLKX and CLKR are required to be present only during actual serial port transfers, and may be stopped (at a valid logic level) when no data is being transferred. Data bits can be transferred in either 8-bit bytes or 16-bit words. Data is clocked out to DX on the rising edges of CLKX, while data is clocked in from DR on the falling edges of CLKR. The MSB of the data is transferred first.

The XSR and RSR are connected to the DXR and DRR, respectively. For transmit operations, the contents of DXR are transferred to XSR when a new transmission begins. For a receive operation, the contents of RSR are transferred to DRR when all of the bits have been received. Thus, the serial port is double-buffered because data may be transferred to or from the DXR or DRR while another transmit or receive operation is being performed.

Serial port transfers on the TMS320C25 are generally initiated by a frame sync pulse. The exception to this is when the continuous mode of operation is used with FSM = 0, as described in a subsequent paragraph. Frame sync pulses are input on FSX for transmit operations and on FSR for receive operations.

The transmit timing diagram is shown in Figure 3–35. The transmit operation begins when data is written into the data transmit register (DXR). The TMS320C2x begins transmitting data when the frame synchronization pulse (FSX) goes low while CLKX is high or going high. The data, starting with the MSB, is then shifted out via the DX pin with the rising edge of CLKX. When all bits have been transmitted, an internal transmit interrupt (XINT) is generated on the rising edge of CLKX. When the serial port is not transmitting, DX is placed in the high-impedance state.

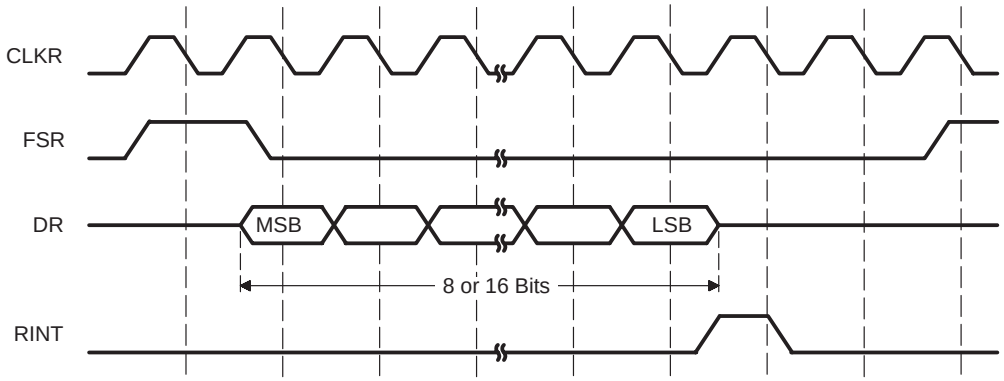
Figure 3–35. Serial Port Transmit Timing Diagram



DX and FSX are unaffected by assertion of the $\overline{\text{HOLD}}$ input. Upon assertion of $\overline{\text{HOLD}}$, any serial port transmission in progress on the DX pin is completed before DX is placed in the high-impedance state. FSX remains configured as either an input or output, remaining low if it is an output.

The receive operation is similar to the transmit operation. The receive timing diagram is shown in Figure 3–36. Reception is initiated by a frame synchronization pulse on the FSR pin. After FSR goes low, data on the DR pin is clocked into the RSR register on the TMS320C25 on every negative-going edge of CLKR. The first data bit is considered the MSB, and RSR is filled accordingly. After all the bits have been received (as specified by FO), an internal receive interrupt (RINT) is generated on the rising edge of CLKR, and the contents of RSR are transferred to DRR.

Figure 3–36. Serial Port Receive Timing Diagram



3.9.2 Timing and Framing Control

Upon completion of a serial port transfer, an internal interrupt is generated. The RINT interrupt is generated for a receive operation, and XINT is generated for a transmit operation. RINT and XINT are generated on the rising edge of CLKR and CLKX, respectively, after the last bit is transferred. Note that if DRR is read before a RINT is received, it will contain the data from the previous operation. Similarly, if DXR is loaded more than once after an XINT is generated (in the continuous transmission mode), only the last value written will be loaded into XSR for the next transmit operation.

When the TMS320C2x is reset, TXM is cleared to zero, and DX is placed in the high-impedance state. Any transmit or receive operation that is in progress when the reset occurs is terminated.

The transmit framing synchronization pulse can be generated internally or externally. The maximum speed of the serial port is 5 MHz. The timing of the serial port signals is compatible with the TI/Intel 29C1x series codecs. The timing is also compatible with the AMI S3506 series codecs if the frame synchronization signals are inverted.

Serial port transfers on the TMS320C25 are generally initiated by a frame sync pulse, except when the continuous mode of operation is used with FSM = 0. Frame sync pulses are input on FSX for transmit operations and on FSR for receive operations. If FSM = 1, frame sync pulses are required; if FSM = 0, they are not required. FSM is set by the SFSM (set frame synchronization mode) instruction and cleared by the RFSM (reset frame synchronization mode) instruction.

3.9.3 Burst-Mode Operation

In burst-mode serial port operation, transfers are separated in time by periods of no serial port activity (the serial port does not operate continuously). For burst-mode operation, FSM must be set to one. Timing of the serial port in this mode of operation is shown in Figure 3–37 and Figure 3–38.

Figure 3–37. Burst-Mode Serial Port Transmit Operation

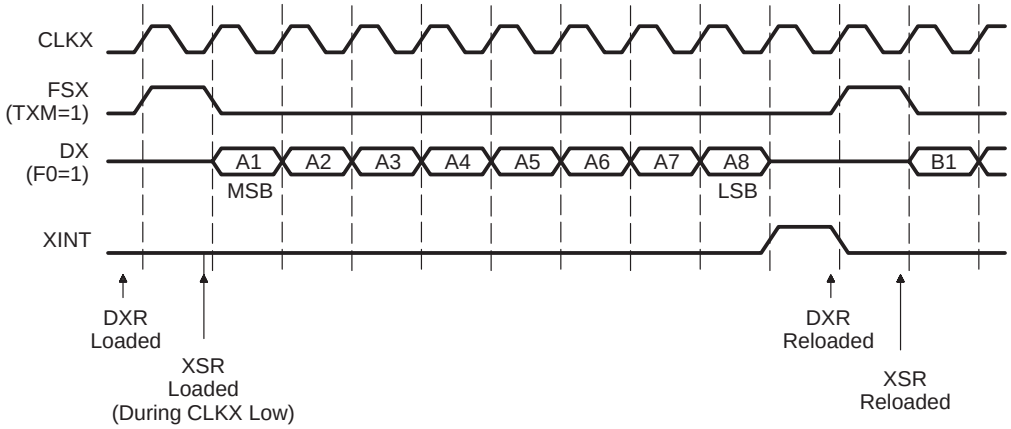
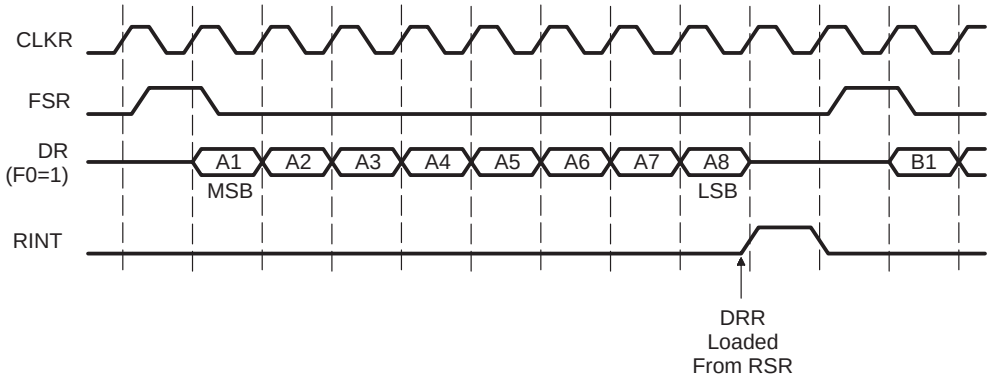


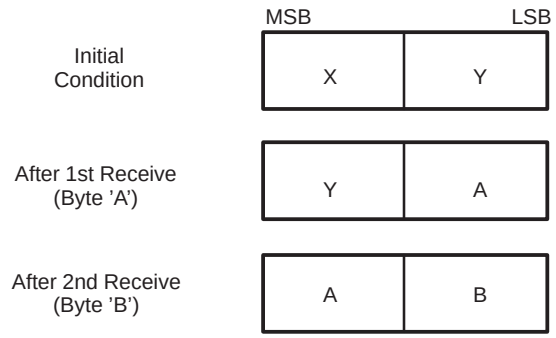
Figure 3–38. Burst-Mode Serial Port Receive Operation



When TXM = 1 (FSX is an output) and the serial port register DXR is loaded, a framing pulse is generated on the next rising edge of CLKX. The XSR is loaded with the current contents of DXR while FSX is high and CLKX is low. Transmission begins when FSX goes low while CLKX is high or is going high. Figure 3–37 shows the timing for the byte mode (FO = 1). XINT is generated on the rising edge of CLKX after all 8 or 16 bits have been transmitted and DX is placed in the high-impedance state. If DXR is reloaded before the next rising edge of CLKX after XINT, FSX will again be generated as shown, and XSR will be reloaded.

The receive operation is similar to the transmit operation. The contents of RSR are loaded into DRR while CLKR is low, just after reception of the last bit sent by the transmitting device (see Figure 3–38). RINT is generated on the next rising edge of CLKR, and DRR may be read at any time before the reception of the final bit of the next transmission. When operating in the byte mode, the eight MSBs of the DRR are the contents of the eight LSBs of the DRR prior to reception of the current byte, as shown in Figure 3–39 for the TMS320C25.

Figure 3–39. Byte-Mode DRR Operation (TMS320C25)



3.9.4 Continuous Operation Using Frame Sync Pulses (TMS320C25)

The TMS320C25 provides two modes of operation that allow the use of a continuous stream of serial data. When FSM = 1, frame sync pulses are required. Because DXR is double-buffered, continuous operation is achieved even if TXM = 1. Writing to DXR during a serial port transmission does not abort the transmission in progress, but, instead, DXR stores that data until XSR can be reloaded. As long as DXR is reloaded before the CLKX rising edge on the final bit being transmitted, the FSX pulse will go high on the rising edge of CLKX during the transmission of the final bit and fall on the next rising edge when transmission of the word just loaded begins. If DXR is not reloaded within this period and FSM = 1, the DX pin will be placed in a high-impedance state for at least one CLKX cycle until DXR is reloaded (as described in the previous section). Figure 3–40 and Figure 3–41 show the timing diagrams for the continuous operation with frame sync pulses.

Figure 3–40. Serial Port Transmit Continuous Operation (FSM = 1)

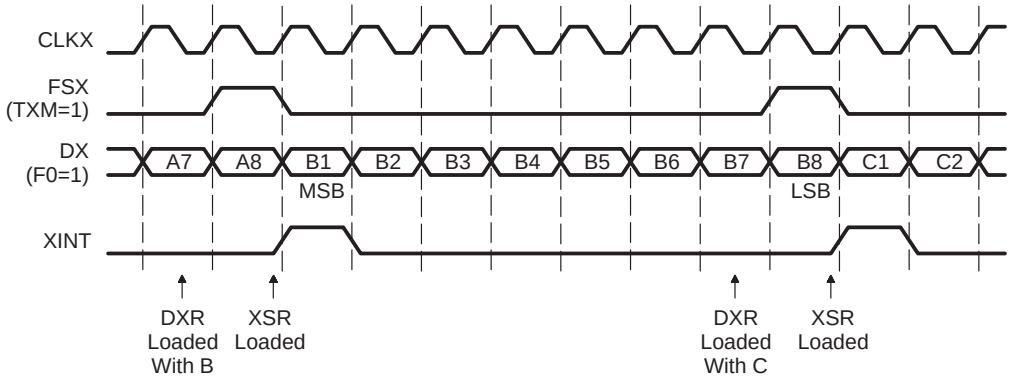
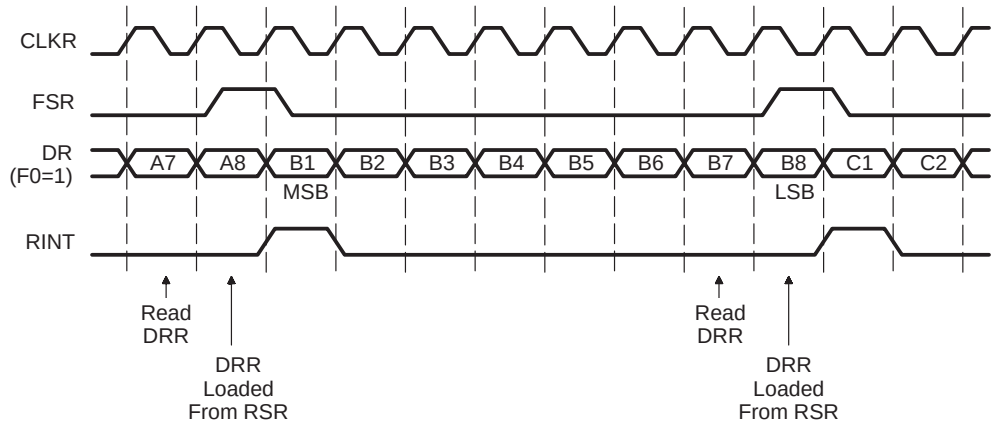


Figure 3–41. Serial Port Receive Continuous Operation (FSM = 1)



Continuous receive operation with FSM = 1 is identical to that of burst-mode operation with the exception that FSR is pulsed during reception of the final bit.

3.9.5 Continuous Operation Without Frame Sync Pulses (TMS320C25)

The continuous mode of operation on the TMS320C25 allows transmission and reception of a continuous bit stream without requiring frame sync pulses every 8 or 16 bits. This mode is selected by setting FSM = 0.

Figure 3–42 and Figure 3–43 show operation of the serial port for both states of TXM to illustrate differences in operation for each case. FSM is initially set to one, and frame sync pulses are required to initiate serial transfers. Before the completion of the transmission (that is, before the next serial port interrupt), the FSM must be reset to zero by means of an RFSM (reset FSM) instruction. RFSM can occur either before or after the write to DXR or read from DRR. From this point on, the FSX and FSR inputs are ignored, with transmission occurring every CLKX cycle and reception occurring every CLKR cycle as long as those clocks are present.

If FSX is configured as an output, it will remain low until FSM is set back to one and DXR is reloaded. If DXR is not reloaded with new data every XINT (every 8 or 16 CLKX cycles, depending on FO), the last value loaded will be transmitted on DX continuously. Note that this is different from the case with FSM = 1 where DX is placed into a high-impedance state if DXR is not reloaded before transmission of the last bit of the current word in XSR. For example, if byte C is not loaded into DXR as indicated in Figure 3–42, bits of byte B (B1–B8) will be retransmitted instead of bits of byte C as shown.

For receive operations, DRR is loaded from RSR (and an RINT is generated) every 8 or 16 CLKR cycles (depending on FO), regardless of whether or not DRR has been read. An overrun of DRR is also possible with FSM = 1 if DRR is not read before the next RINT. The only way to stop continuous transmission or reception once started, when FSM = 0, is either to stop CLKX or CLKR or to perform an SFSM (set FSM) instruction.

Continuous transmission without frame sync pulses is very useful in communicating directly to telephone system PCM highways. For ATT T1 and CCITT G711/712 lines, FSX and FSR pulses are generated only every 24 or 32 bytes. By counting the transmitted and received bytes in software after an initial FSX or FSR and performing SFSM and RFSM instructions as required, the TMS320C25 can easily be made to communicate in these formats.

Figure 3–42. Serial Port Transmit Continuous Operation (FSM = 0)

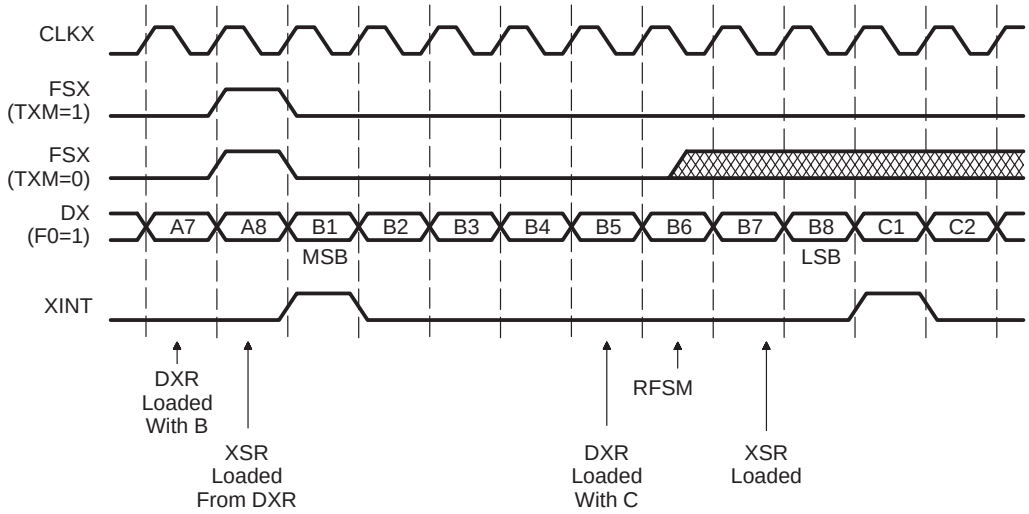
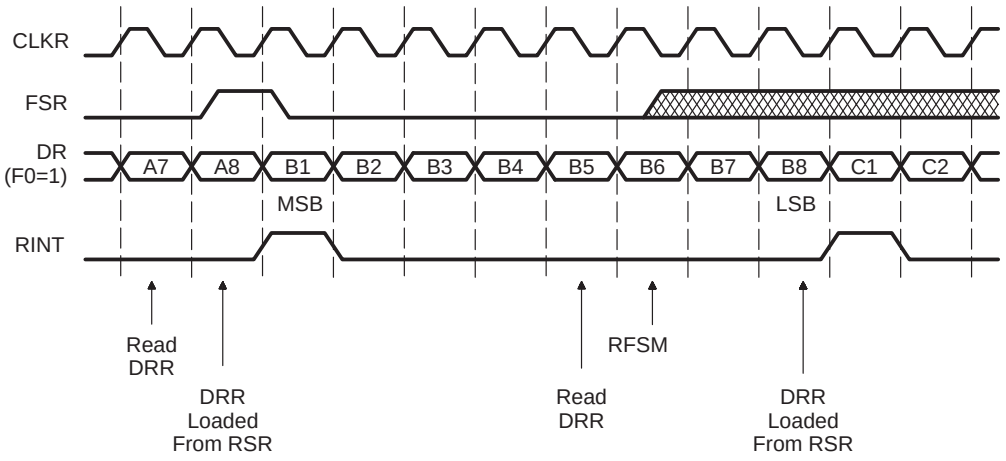


Figure 3–43. Serial Port Receive Continuous Operation (FSM = 0)



3.9.6 Initialization of Continuous Operation Without Frame Sync Pulses

FSM is normally initialized during an XINT or RINT service routine to enable or disable FSX and FSR, respectively, for the next serial port operation. It is necessary to start this mode with FSM = 1 so that the first data transferred out of the serial port is the data written to the DXR register. Otherwise, the serial port starts transmitting the contents of the shift register before loading it with the value stored in the DXR register. Upon each completion of a data packet transmission, it loads the data contained in the DXR register into the shift register and continues transmitting. After the first frame pulse has been generated by or sent to the TMS320C25, the FSM bit must be reset to 0 using the RFSM instruction. This must be done before the next serial port interrupt to ensure continuous transmission. If continuous transmission is stopped via software, this initiation sequence must be repeated to restart the continuous mode operation.

As shown in Figure 3–44 and Figure 3–45, RFSM may occur before a write to DXR, regardless of the state of TXM. If TXM = 1, FSX is generated in a normal manner on the next rising edge of CLKX, but only once. If TXM = 0, the TMS320C25 waits to transmit until FSX is pulsed, but from then on, the FSX input is ignored. Note that just as in the case of continuous-mode operation without sync pulses described in subsection 3.9.5, the first data written to DXR (byte A) is output twice unless DXR is reloaded before the second transmission is started. It is important to consider this dummy cycle when using continuous-mode serial operation.

The receive timings are the same as those for the transmit operations with TXM = 0. The TMS320C25 waits to receive data until FSR is pulsed, but thereafter the FSR input is ignored. No dummy cycle is associated with the receive operation; this is because DRR has a post-buffering nature as opposed to the prebuffering nature of DXR.

Figure 3–44. Continuous Transmit Operation Initialization

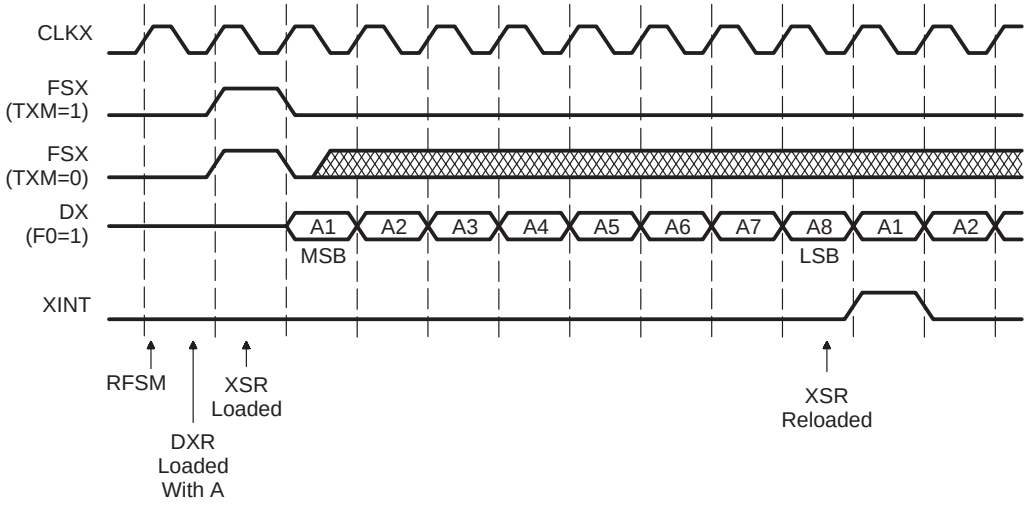
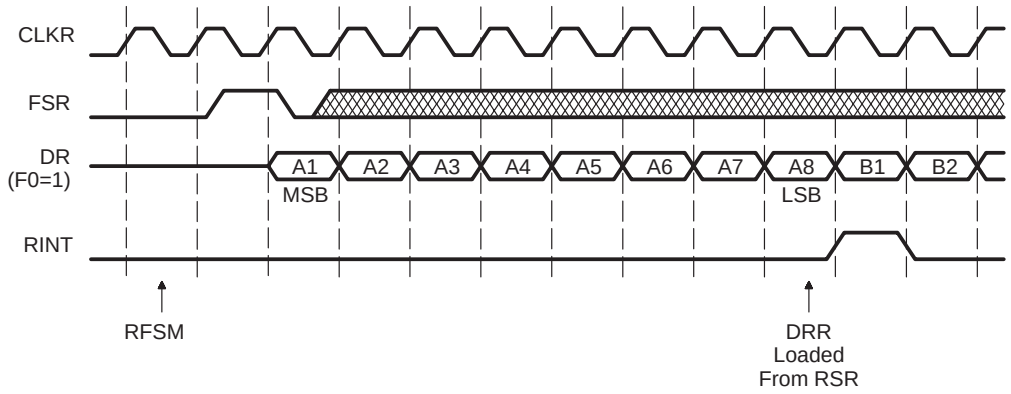


Figure 3–45. Continuous Receive Operation Initialization



3.10 Multiprocessing and Direct Memory Access (DMA)

The flexibility of the TMS320C2x allows configurations to satisfy a wide range of system requirements. Some of the system configurations using the TMS320C2x are as follows:

- A standalone system (single processor),
- A multiprocessor with devices in parallel,
- A host/slave multiprocessor with shared global data memory space, or
- A peripheral processor interfaced using processor-controlled signals to another device.

These system configurations are made possible by three specialized features of the TMS320C2x: the synchronization function utilizing the $\overline{\text{SYNC}}$ input, the global memory interface, and the hold function implemented with the $\overline{\text{HOLD}}$ and $\overline{\text{HOLDA}}$ pins. The following sections describe these functions in detail.

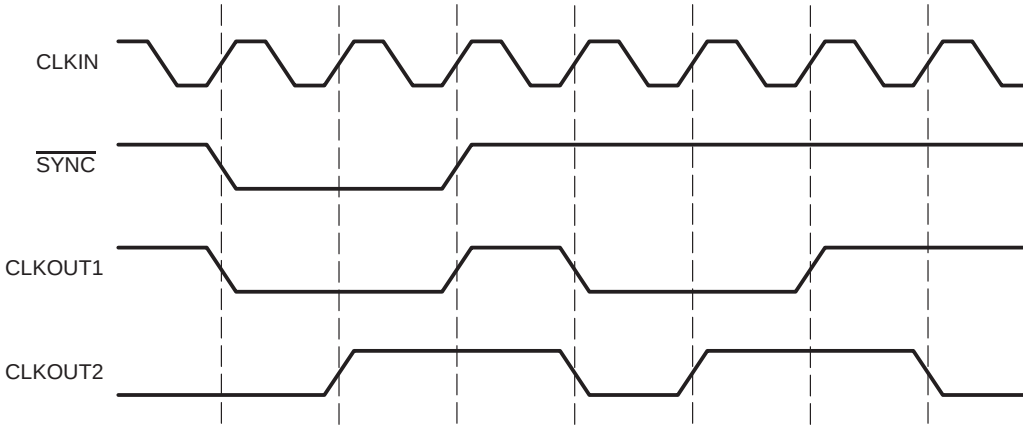
3.10.1 Synchronization

In a multiprocessor environment, the $\overline{\text{SYNC}}$ input can be used to greatly ease interface between processors. This input is used to cause each TMS320C2x in the system to synchronize its internal clock, thereby allowing the processors to run in lock-step operation.

Multiple TMS320C2x devices are synchronized by using common $\overline{\text{SYNC}}$ and external clock inputs. A negative transition on $\overline{\text{SYNC}}$ sets each processor to internal quarter-phase one (Q1). This transition must occur synchronously with the rising edge of CLKIN. On the TMS320C25, there is a two-CLKIN-cycle delay following the cycle in which $\overline{\text{SYNC}}$ goes low, before the synchronized Q1 occurs.

The timing diagram for the $\overline{\text{SYNC}}$ input is shown in Figure 3–46 for the TMS320C2x.

Figure 3–46. Synchronization Timing Diagram (TMS320C25)



Normally, $\overline{\text{SYNC}}$ is applied while $\overline{\text{RS}}$ is active. If $\overline{\text{SYNC}}$ is asserted after a reset, the following can occur:

1) The processor machine cycle is reset to Q1, provided that the timing requirements for $\overline{\text{SYNC}}$ are met. If $\overline{\text{SYNC}}$ is asserted at the beginning of Q1, Q3, or Q4, the current instruction is improperly executed. If $\overline{\text{SYNC}}$ is asserted at the beginning of Q2, the current instruction is executed properly.

2) If $\overline{\text{SYNC}}$ does not meet the timing requirements, unpredictable processor operation occurs. A reset should then be executed to place the processor back in a known state.

3.10.2 Global Memory

For multiprocessing applications, the TMS320C2x is capable of allocating global data memory space and communicating with that space via the BR (bus request) and READY control signals.

Global memory is memory shared by more than one processor; therefore, access to it must be arbitrated. When using global memory, the processor's address space is divided into local and global sections. The local section is used by the processor to perform its individual function, and the global section is used to communicate with other processors.

A memory-mapped global memory allocation register (GREG) specifies part of the TMS320C2x's data memory as global external memory. GREG, which is memory-mapped at data memory address location 5, is an eight-bit register connected to the eight LSBs of the internal D bus. The upper eight bits of location 5 are nonexistent and read as 1s.

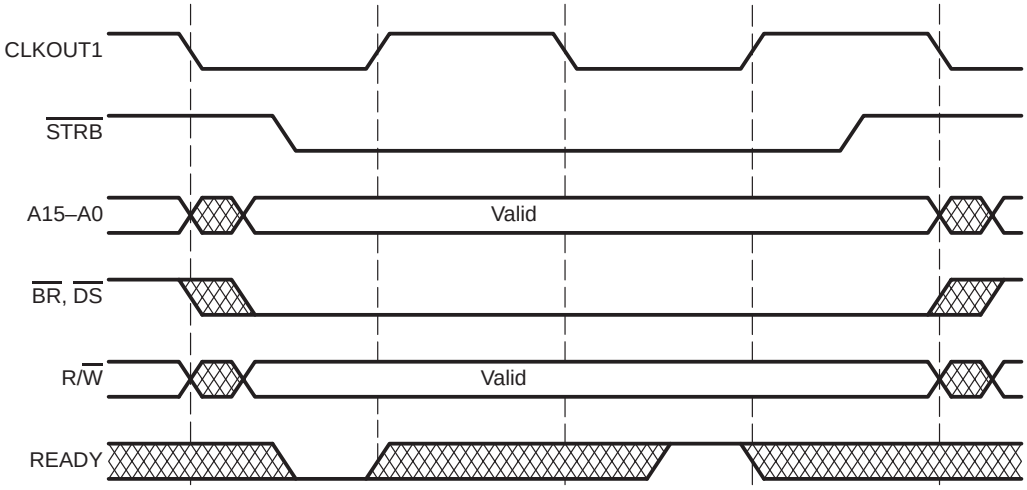
The contents of GREG determine the size of the global memory space. The legal values of GREG and corresponding global memory spaces are shown in Table 3–9. Note that values other than those listed in the table lead to fragmented memory maps.

Table 3–9. Global Data Memory Configurations

GREG Value	Local Memory		Global Memory	
	Range	# Words	Range	# Words
000000XX	0h – 0FFFFh	65,536	----------	0
10000000	0h – 07FFFh	32,768	08000h – 0FFFFh	32,768
11000000	0h – 0BFFFh	49,152	0C000h – 0FFFFh	16,384
11100000	0h – 0DFFFh	57,344	0E000h – 0FFFFh	8,192
11110000	0h – 0EFFFh	61,440	0F000h – 0FFFFh	4,096
11111000	0h – 0F7FFh	63,488	0F800h – 0FFFFh	2,048
11111100	0h – 0FBFFh	64,512	0FC00h – 0FFFFh	1,024
11111110	0h – 0FDFFh	65,024	0FE00h – 0FFFFh	512
11111111	0h – 0FEFFh	65,280	0FF00h – 0FFFFh	256

When a data memory address, either direct or indirect, corresponds to a global data memory address (as defined by GREG), $\overline{BR}$ is asserted low with DS to indicate that the processor wishes to make a global memory access. External logic then arbitrates for control of the global memory, asserting READY when the TMS320C2x has control. The length of the memory cycle is controlled by the READY line. One wait-state timing is shown in Figure 3–47. Note that all signals not shown have the same timing as in the normal read or write case.

Figure 3–47. Global Memory Access Timing



3.10.3 The Hold Function

The TMS320C2x supports direct memory access (DMA) to its local (off-chip) program, data, and I/O spaces. Two signals, $\overline{\text{HOLD}}$ and $\overline{\text{HOLDA}}$, are provided to allow another device to take control of the processor's buses. Upon receiving a $\overline{\text{HOLD}}$ signal from an external device, the processor acknowledges by bringing $\overline{\text{HOLDA}}$ low. The processor then places its address and data buses as well as all control signals ($\overline{\text{PS}}$, $\overline{\text{DS}}$, $\overline{\text{IS}}$, R/$\overline{\text{W}}$, and $\overline{\text{STRB}}$) in the high-impedance state. The serial port output pins, DX and FSX, are not affected by $\overline{\text{HOLD}}$. Signaling between the external processor and the TMS320C2x can be performed by using interrupts.

The timing for the $\overline{\text{HOLD}}$ and $\overline{\text{HOLDA}}$ signals is shown in Figure 3–48. $\overline{\text{HOLD}}$ has the same setup time as READY and is sampled at the beginning of quarter-phase 3. If the setup time is met, it takes three machine cycles before the buses and control signals go to the high-impedance state. Note that unlike the external interrupts ($\overline{\text{INT}}$2 – $\overline{\text{INT}}$0), $\overline{\text{HOLD}}$ is not a latched input. The external device must keep $\overline{\text{HOLD}}$ low until it receives a $\overline{\text{HOLDA}}$ from the TMS320C2x.

If the TMS320C2x is in the middle of a multicycle instruction, it will finish the instruction before entering the hold state. After the instruction is completed, the buses are placed in the high-impedance state. This also applies to instructions that become multicycle due to insertion of wait states or to the use of RPT/RPTK instructions.

After $\overline{\text{HOLD}}$ is deasserted, program execution resumes from the same point at which it was halted. $\overline{\text{HOLDA}}$ is removed synchronously with $\overline{\text{HOLD}}$, as shown in Figure 3–48. If the setup time is met, two machine cycles are required before the buses and control signals become valid.

$\overline{\text{HOLD}}$ is not treated as an interrupt. If the TMS320C2x was executing the IDLE instruction before entering the hold state, it resumes executing IDLE once it leaves the hold state.

The hold function on the TMS320C25 has two distinct operating modes:

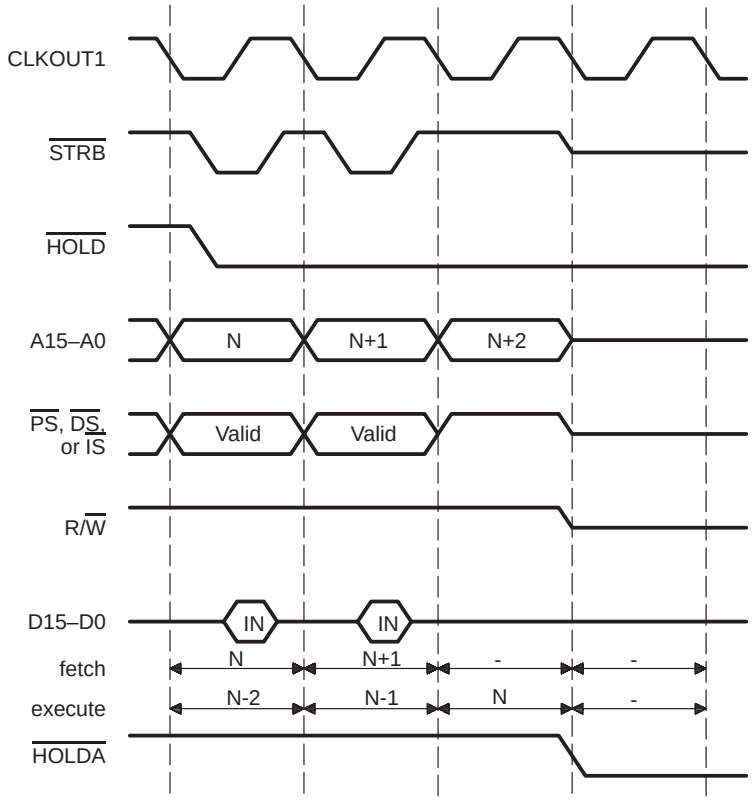
- A mode in which execution is suspended during assertion of $\overline{\text{HOLD}}$, and
- A TMS320C25 concurrent DMA mode, in which the TMS320C25 continues to execute its program while operating from internal RAM or ROM, thus greatly increasing throughput in data-intensive applications.

The operating mode is selected by the HM (hold mode) status register bit on the TMS320C25. The $\overline{\text{HOLD}}$ signal is pulled low, as shown in the first part of Figure 3–48. When HM = 1, the TMS320C25 halts program execution and enters the hold state directly. When HM = 0, the processor enters the hold state directly, as shown in Figure 3–48, if program execution is from external memory or if external data memory is being accessed. If program execution is from internal memory, however, and if no external data memory accesses are required, the processor enters the hold state externally, but program execution continues internally. This allows more efficient system operation because a program may continue executing while an external DMA operation is being performed.

Program execution ceases until $\overline{\text{HOLD}}$ is removed if the processor is in a hold state with HM = 0 and an internally executing program requires an external access, or if the program branches to an external address. Also, if a repeat instruction that requires the use of the external bus is executing with HM = 0 and a hold occurs, the hold state is entered after the current bus cycle. If this situation occurs with HM = 1, the hold state will not be entered until the repeat count is completed. HM is set and reset by the SHM (set hold mode) and RHM (reset hold mode) instructions, respectively.

All interrupts are disabled while $\overline{\text{HOLD}}$ is active with HM = 1. If an interrupt is received during this period, the interrupt is latched and remains pending. Therefore, $\overline{\text{HOLD}}$ itself does not affect any interrupt flags or registers. When HM = 0, interrupts function normally.

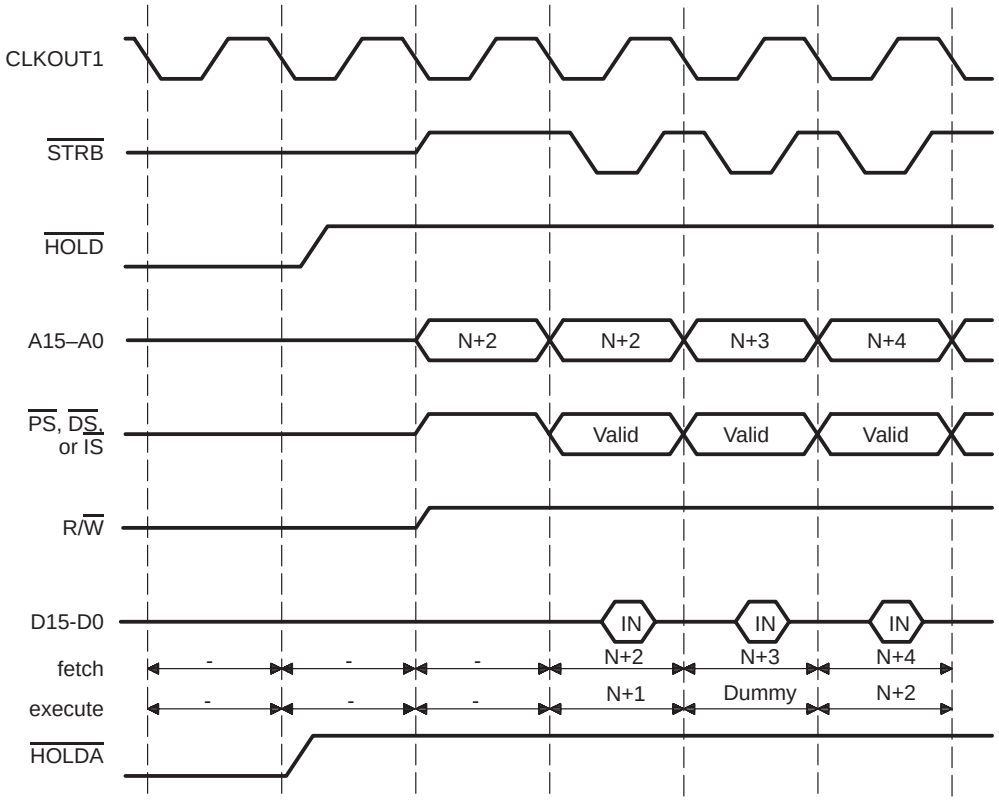
Figure 3–48. TMS320C25 Hold Timing Diagram



Notes: 1) N is the program memory location for the current instruction.

2) This example shows only the execution of single-cycle instructions fetched from external program memory.

Figure 3–48. TMS320C25 Hold Timing Diagram (Continued)



Notes: 3) N is the program memory location for the current instruction.

4) This example shows only the execution of single-cycle instructions fetched from external program memory.

3.11 General Description of the TMS320C26

The TMS320C26 is a spin-off of the TMS320C25. It is processed in CMOS technology, is capable of an instruction cycle time of 100 ns, and is pin-for-pin and object code-compatible with the TMS320C25, with the exception of the instructions for on-chip-memory configuration. The TMS320C26's enhancement over the TMS320C25 is basically the larger on-chip RAM (see the block diagram in Figure 3–3), divided into 4 blocks with 1568 words altogether. The three blocks, B0, B1, and B3—each with 512 $\times$ 16 bits—are configurable as data or program memory. The block B2 with 32 $\times$ 16 bits is identical with the same block of the TMS320C25 and is usable as data memory. The ROM of the TMS320C26 consists of 256 words with a factory-programmed bootloader.

In many applications, the large internal memory of the TMS320C26 allows you to build single-chip solutions with all data and programs internal and the option to reload programs or algorithms. A memory size of 1568 words allows the TMS320C26 to handle a data array of, for example, 1024 words with an on-chip program RAM of 512 words and additional 32 words of data RAM. When using internal blocks as program memory, instructions can be downloaded from external program memory into on-chip RAM and then executed. The TMS320C26 allows the DMOV function in all internal data memory blocks. An FIR filter programmed with the MAC or MACD instructions can use the internal program RAM for storing the coefficients.

3.12 General Description of the TMS320C28

The TMS320C28 is the newest member of the TMS320C2x family. Like the TMS320C26, it is also processed in CMOS technology, is capable of 100-ns instruction cycle time, and is object code-compatible with the TMS320C25. The enhancements of the TMS320C28 over the TMS320C25 are the larger on-chip ROM (8K words) and a new powerdown mode. The TMS320C28 comes in an 80-pin QFP package that includes three new pins ($\overline{\text{PDI}}$, PDACK, and $\overline{\text{WAKEUP}}$) to support the powerdown feature. This mode decreases the current to about 100 μA compared with the 50-mA current in the TMS320C25 idle mode. See Appendix C for more details about the TMS320C28 powerdown feature. The TMS320C28 has more on-chip memory (8K-word ROM and 544-word RAM) than the TMS320C26. The 8K-word on-chip ROM reduces system cost and allows large programs to execute at full speed from memory. The large internal memory and the powerdown feature of the TMS320C28 allow you to build a single-chip solution with all data and programs internal, while conserving power.

Chapter 4

Assembly Language Instructions

The TMS320C2x instruction set supports numeric-intensive signal processing operations as well as general-purpose applications, such as multiprocessing and high-speed control. TMS320C1x source code is upward-compatible with TMS320C2x source code.

The TMS320C26 is similar to the TMS320C25 except for its internal memory configuration. This is discussed in Section 3.4 and in Appendix B.

This chapter describes the assembly language instructions for the TMS320C2x microprocessor. Topics include:

Topic **Page**

4.1 Memory Addressing Modes 4-2

4.2 Instruction Set 4-11

4.3 Individual Instruction Descriptions 4-18

4.1 Memory Addressing Modes

The TMS320C2x instruction set provides three memory addressing modes:

- Direct addressing mode
- Indirect addressing mode
- Immediate addressing mode

Both direct and indirect addressing can be used to access data memory. Direct addressing concatenates seven bits of the instruction word with the nine bits of the data memory page pointer to form the 16-bit data memory address. Indirect addressing accesses data memory through the auxiliary registers. In immediate addressing, the data is based on a portion of the instruction word(s). The following sections describe each addressing mode and give the opcode formats and some examples for each mode.

4.1.1 Direct Addressing Mode

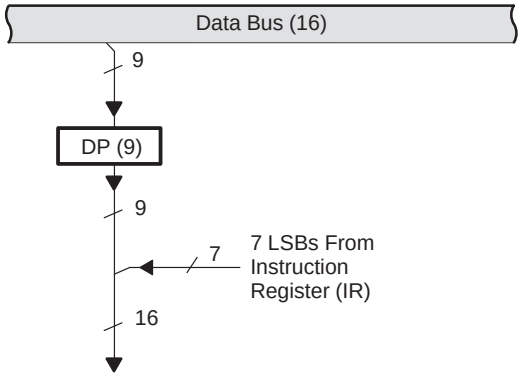
In the direct memory addressing mode, the instruction word contains the lower seven bits of the data memory address (dma). This field is concatenated with the nine bits of the data memory page pointer (DP) register to form the full 16-bit data memory address. Thus, the DP register points to one of 512 possible 128-word data memory pages, and the 7-bit address in the instruction points to the specific location within that data memory page. The DP register is loaded through the LDP (load data memory page pointer), LDPK (load data memory page pointer immediate), or LST (load status register ST0) instructions.

Note:

The data page pointer is not initialized by reset and is therefore undefined after powerup. The TMS320C2x development tools, however, utilize default values for many parameters, including the data page pointer. Because of this, programs that do not explicitly initialize the data page pointer may execute improperly, depending on whether they are executed on a TMS320C2x device or by using a development tool. Thus, it is critical that all programs initialize the data page pointer in software.

Figure 4–1 illustrates how the 16-bit data address is formed.

Figure 4–1. Direct Addressing Block Diagram



Direct addressing can be used with all instructions except CALL, the branch instructions, immediate operand instructions, and instructions with no operands. The direct addressing format is as follows:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Opcode								0	dma						

Bits 15 through 8 contain the opcode. Bit 7 = 0 defines the addressing mode as direct, and bits 6 through 0 contain the data memory address (dma).

Example of Direct Addressing Format:

ADD 9,5 Add to accumulator the contents of data memory location 9 left-shifted 5 bits.

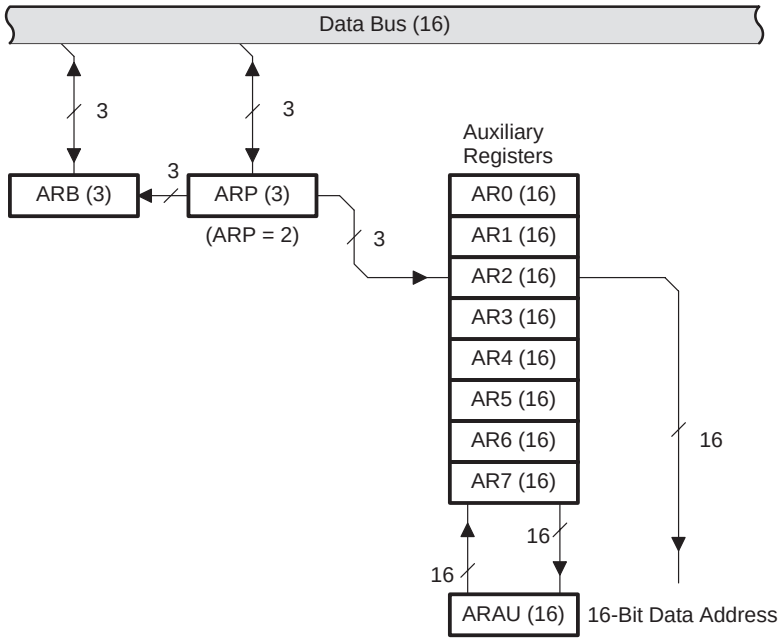
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1

The opcode of the ADD 9,5 instruction is 05h and appears in bits 15 through 8. The notation nnh indicates nn is a hexadecimal number. The shift count of 5h appears in bits 11 through 8 of the opcode. The data memory address 09h appears in bits 6 through 0.

4.1.2 Indirect Addressing Mode

The auxiliary registers (AR) provide flexible and powerful indirect addressing. Eight auxiliary registers (AR0–AR7) are provided on the TMS320C2x. To select a specific auxiliary register, the auxiliary register pointer (ARP) is loaded with a value from 0 through 7 designating AR0 through AR7 (see Figure 4–2).

Figure 4–2. Indirect Addressing Block Diagram



The contents of the auxiliary registers may be operated upon by the auxiliary register arithmetic unit (ARAU), which implements 16-bit unsigned arithmetic. The ARAU performs auxiliary register arithmetic operations in the same cycle as the execution of the instruction. (Note that the increment or decrement of the indicated AR is always executed after the use of that AR in the instruction.)

In indirect addressing, any location in the 64K data memory space can be accessed via the 16-bit addresses contained in the auxiliary registers. These can be loaded by the instructions LAR (load auxiliary register), LARK (load auxiliary register immediate), and LRLK (load auxiliary register long immediate). The auxiliary registers on the TMS320C2x can be modified by ADRK (add to auxiliary register short immediate) or SBRK (subtract from auxiliary register short immediate). The TMS320C2x auxiliary registers can also be modified by the MAR (modify auxiliary register) instruction or, equivalently, by the indirect addressing field of any instruction supporting indirect addressing. AR(ARP) denotes the auxiliary register selected by ARP.

The following symbols are used in indirect addressing, including bit-reversed (BR) addressing:

*****	Contents of AR(ARP) are used as the data memory address.
***–**	Contents of AR(ARP) are used as the data memory address, then decremented after the access.
***+**	Contents of AR(ARP) are used as the data memory address, then incremented after the access.
***0–**	Contents of AR(ARP) are used as the data memory address, and the contents of AR0 subtracted from it after the access.
***0+**	Contents of AR(ARP) are used as the data memory address, and the contents of AR0 added to it after the access.
***BR0–**	Contents of AR(ARP) are used as the data memory address, and the contents of AR0 subtracted from it, with reverse carry (rc) propagation, after the access.
***BR0+**	Contents of AR(ARP) are used as the data memory address, and the contents of AR0 added to it, with reverse carry (rc) propagation, after the access.

There are two main types of indirect addressing with indexing:

- ❑ Regular indirect addressing with increment or decrement, and
- ❑ Indirect addressing with indexing based on the value of AR0:
  Indexing by adding or subtracting the contents of AR0, or
  Indexing by adding or subtracting the contents of AR0 with the carry propagation reversed (for FFTs on the TMS320C2x).

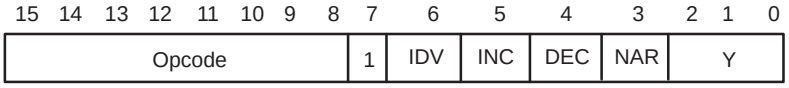
In either case, the contents of the auxiliary register pointed to by the ARP register are used as the address of the data memory operand. Then, the ARAU performs the specified mathematical operation on the indicated auxiliary register. Additionally, the ARP may be loaded with a new value. All indexing operations are performed on the current auxiliary register in the same cycle as the original instruction.

Indirect auxiliary register addressing allows for post-access adjustments of the auxiliary register pointed to by the ARP. The adjustment may be an increment or decrement by one, or it may be based upon the contents of AR0.

Bit-reversed addressing modes on the TMS320C2x allow efficient I/O to be performed for the resequencing of data points in a radix-2 FFT program. The direction of carry propagation in the ARAU is reversed when this mode is selected and AR0 is added to/subtracted from the current auxiliary register. Typical use of this addressing mode requires that AR0 first be set to a value corre-

sponding to one-half of the array size, and AR(ARP) be set to the base address of the data (the first data point). See subsection 5.7.4 for an FFT example using bit-reversed addressing modes.

Indirect addressing can be used with all instructions except immediate operand instructions and instructions with no operands. The indirect addressing format is as follows:



Bits 15 through 8 contain the opcode, and bit 7 = 1 defines the addressing mode as indirect. Bits 6 through 0 contain the indirect addressing control bits.

Bit 6 contains the increment/decrement value (IDV). The IDV determines whether AR0 will be used to increment or decrement the current auxiliary register. If bit 6 = 0, an increment or decrement (if any) by one occurs to the current auxiliary register. If bit 6 = 1, AR0 may be added to or subtracted from the current auxiliary register as defined by bits 5 and 4.

Bits 5 and 4 control the arithmetic operation to be performed with AR(ARP) and AR0. When set, bit 5 indicates that an increment is to be performed. If bit 4 is set, a decrement is to be performed. Table 4–1 shows the correspondence of bit pattern and arithmetic operation.

Table 4–1. Indirect Addressing Arithmetic Operations

Bits			Arithmetic Operation
6	**5**	**4**	
0	0	0	No operation on AR(ARP)
0	0	1	AR(ARP) – 1 → AR(ARP)
0	1	0	AR(ARP) + 1 → AR(ARP)
0	1	1	Reserved
1	0	0	AR(ARP) – AR0 → AR(ARP) [reverse carry propagation]
1	0	1	AR(ARP) – AR0 → AR(ARP)
1	1	0	AR(ARP) + AR0 → AR(ARP)
1	1	1	AR(ARP) + AR0 → AR(ARP) [reverse carry propagation]

Bit 3 and bits 2 through 0 control the auxiliary register pointer (ARP). Bit 3 (NAR) determines if a new value is loaded into the ARP. If bit 3 = 1, the contents of bits 2 through 0 (Y = next ARP) are loaded into the ARP. If bit 3 = 0, the contents of the ARP remain unchanged.

Table 4–2 shows the bit fields, notation, and operation used for indirect addressing. For some instructions, the notation in Table 4–2 includes a shift code: for example, *0+,8,3 where 8 is the shift code and Y = 3.

Table 4–2. Bit Fields for Indirect Addressing

Instruction Field Bits 15 – 8 7 6 5 4 3 2 1 0	Notation	Operation
← Opcode →1 0 0 0 0 ← Y →	*	No manipulation of ARs/ARP
← Opcode →1 0 0 0 1 ← Y →	*,Y	Y → ARP
← Opcode →1 0 0 1 0 ← Y →	*–	AR(ARP) –1 → AR(ARP)
← Opcode →1 0 0 1 1 ← Y →	*–,Y	AR(ARP) –1 → AR(ARP) Y → ARP
← Opcode →1 0 1 0 0 ← Y →	*+	AR(ARP) +1 → AR(ARP)
← Opcode →1 0 1 0 1 ← Y →	*+,Y	AR(ARP)+1 → AR(ARP) Y → ARP
← Opcode →1 1 0 0 0 ← Y →	*BR0–	AR(ARP)–rcAR0 → AR(ARP)
← Opcode →1 1 0 0 1 ← Y →	*BR0–,Y	AR(ARP)–rcAR0 → AR(ARP) Y → ARP
← Opcode →1 1 0 1 0 ← Y →	*0–	AR(ARP)–AR0 → AR(ARP)
← Opcode →1 1 0 1 1 ← Y →	*0–,Y	AR(ARP)–AR0 → AR(ARP) Y → RP
← Opcode →1 1 1 0 0 ← Y →	*0+	AR(ARP)+AR0 → AR(ARP)
← Opcode →1 1 1 0 1 ← Y →	*0+,Y	AR(ARP)+AR0 → AR(ARP) Y → ARP
← Opcode →1 1 1 1 0 ← Y →	*BR0+	AR(ARP)+rcAR0 → AR(ARP)
← Opcode →1 1 1 1 1 ← Y →	*BR0+,Y	AR(ARP)+rcAR0 → AR(ARP) Y → ARP

The CMPR (compare auxiliary register with AR0), and BBZ/BBNZ (branch if TC bit equal/not equal to zero) instructions facilitate conditional branches based on comparisons between the contents of AR0 and the contents of AR(ARP).

The auxiliary registers may also be used for temporary storage via the load and store auxiliary register instructions, LAR and SAR, respectively.

The following examples illustrate the indirect addressing format:

Example 1 **ADD *+,8** Add to the accumulator the contents of the data memory address defined by the contents of the current auxiliary register. This data is left-shifted 8 bits before being added. The current auxiliary register is autoincremented by one. The opcode is 08A0h, as shown below.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0

Example 2 **ADD *,8** As in Example 1, but with no autoincrement; the opcode is 0880h.

Example 3 **ADD *–,8** As in Example 1, except that the current auxiliary register is decremented by one; the opcode is 0890h.

Example 4 **ADD *0+,8** As in Example 1, except that the contents of auxiliary register AR0 are added to the current auxiliary register; the opcode is 08E0h.

Example 5 **ADD *0–,8** As in Example 1, except that the contents of auxiliary register AR0 are subtracted from the current auxiliary register; the opcode is 08D0h.

Example 6 **ADD *+,8,3** As in Example 1, except that the auxiliary register pointer (ARP) is loaded with the value 3 for subsequent instructions;the opcode is 08ABh.

Example 7 **ADD *BR0–,8** The contents of auxiliary register AR0 are subtracted from the current auxiliary register with reverse carry propagation; the opcode is 08C0h.

Example 8 **ADD *BR0+,8** The contents of auxiliary register AR0 are added to the current auxiliary register with reverse carry propagation; the opcode is 08F0h.

4.1.3 Immediate Addressing Mode

In immediate addressing, the instruction word(s) contains the value of the immediate operand. The TMS320C2x has both single-word (8-bit and 13-bit constant) short immediate instructions and two-word (16-bit constant) long immediate instructions. The immediate operand is contained within the instruction word itself in short immediate instructions. In long immediate instructions, the word following the instruction opcode is used as the immediate operand.

The following short immediate instructions contain the immediate operand in the instruction word and execute within a single instruction cycle. The length of the constant operand is instruction-dependent.

ADDK Add to accumulator short immediate (8-bit absolute constant)

ADRK Add to auxiliary register short immediate (8-bit absolute constant)

LACK Load accumulator short immediate (8-bit absolute constant)

LARK Load auxiliary register short immediate (8-bit absolute constant)

LARP Load auxiliary register pointer (3-bit constant)

LDPK Load data memory page pointer immediate (9-bit constant)

MPYK Multiply immediate (13-bit 2s-complement constant)

RPTK Repeat instruction as specified by immediate value (8-bit constant)

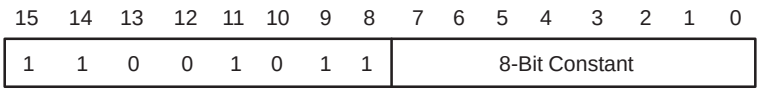
SBRK Subtract from auxiliary register short immediate (8-bit absolute constant)

SUBK Subtract from accumulator short immediate (8-bit absolute constant).

Example of short immediate addressing format:

RPTK 99 Execute the instruction following this instruction 100 times.

With the RPTK instruction, the immediate operand is contained as a part of the instruction opcode. The instruction format for RPTK is as follows:



For long immediate instructions, the constant is a 16-bit value in the word following the opcode. The 16-bit value can be optionally used as an absolute constant or as a 2s-complement value.

ADLK Add to accumulator long immediate with shift (absolute or 2s complement)

ANDK AND immediate with accumulator with shift

LALK Load accumulator long immediate with shift (absolute or 2s complement)

LRLK Load auxiliary register long immediate

ORK OR immediate with accumulator with shift

SBLK Subtract from accumulator long immediate with shift (absolute or 2s complement)

XORK Exclusive-OR immediate with accumulator with shift.

Example of long immediate addressing format:

ADLK 16384,2 Add to the accumulator the value 16384 with a shift to the left of two, effectively adding 65536 to the contents of the accumulator.

The ADLK instruction uses the word following the instruction opcode as the immediate operand. The instruction format for ADLK is as follows:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	Shift				0	0	0	0	0	0	1	0
16-Bit Constant															

4.2 Instruction Set

The following sections list the symbols and abbreviations used in the instruction set summary and in the instruction descriptions. The complete instruction set summary is organized according to function. A detailed description of each instruction is listed in the instruction set summary.

4.2.1 Symbols and Abbreviations

Table 4–3 lists symbols and abbreviations used in the instruction set summary (in Table 4–4) and the individual instruction descriptions.

Table 4–3. Instruction Symbols

Symbol	Meaning
A	Port address
ACC	Accumulator
ARB	Auxiliary register pointer buffer
ARn	Auxiliary register n (AR0, AR1 assembler symbols equal to 0 or 1)
ARP	Auxiliary register pointer
B	4-bit field specifying a bit code
BIO	Branch control input
C	Carry bit
CM	2-bit field specifying compare mode
CNF	On-chip RAM configuration control bit
D	Data memory address field
DATn	Label assigned to data memory location n
dma	Data memory address
DP	Data page pointer
FO	Format status bit
FSM	Frame synchronization mode bit
HM	Hold mode bit
INTM	Interrupt mode flag bit
K	Immediate operand field
M	Addressing mode bit
MCS	Microcall stack
nnh	nnh = hexadecimal number (others are decimal values)
OV	Overflow mode flag bit
OVM	Overflow mode bit
P	Product register
PA	Port address (PA0–PA15 assembler symbols equal to 0 through 15)
PC	Program counter
PFC	Prefetch counter
PM	2-bit field specifying P register output shift code
pma	Program memory address
PRGn	Label assigned to program memory location n
R	3-bit operand field specifying auxiliary register
RPTC	Repeat counter
S	4-bit left-shift code
STn	Status register n (ST0 or ST1)
SXM	Sign-extension mode bit
T	Temporary register
TC	Test control bit
TOS	Top of stack
TXM	Transmit mode bit
X	3-bit accumulator left-shift field
XF	XF pin status bit

Table 4–3. Instruction Symbols (Continued)

Symbol	Meaning
→	Is assigned to
| |	An absolute value
italics	User-defined items
[ ]	Optional items
( )	Contents of
{ }	Alternative items, one of which must be entered
	Blanks or spaces must be entered where shown.

4.2.2 Instruction Set Summary

Table 4–4 shows the instruction set summary for the TMS320C2x processor, which is a superset of the TMS320C1x instruction set. Included in the instruction set are four special groups of instructions to improve overall processor throughput and ease of use.

- Extended-precision arithmetic (ADDC, SUBB, MPYU, BC, BNC, SC, and RC)
- Adaptive filtering (MPYA, MPYS, and ZALR)
- Control and I/O (RHM, SHM, RTC, STC, RFSM, and SFSM)
- Accumulator and register (SPH, SPL, ADDK, SUBK, ADRK, SBRK, ROL, and ROR).

The instruction set summary is arranged according to function and alphabetized within each functional grouping. Additional information is presented in the individual instruction descriptions in the following section.

Table 4–4. Instruction Set Summary

ACCUMULATOR MEMORY REFERENCE INSTRUCTIONS						
Mnemonic and Description		**Words**	**16-Bit Opcode**			
			MSB			**LSB**
ABS	Absolute value of accumulator	1	1100	1110	0001	1011
ADD	Add to accumulator with shift	1	0000	SSSS	MDDD	DDDD
ADDC	Add to accumulator with carry	1	0100	0011	MDDD	DDDD
ADDH	Add to high accumulator	1	0100	1000	MDDD	DDDD
ADDK	Add to accumulator short immediate	1	1100	1100	KKKK	KKKK
ADDS	Add to low accumulator with sign-extension suppressed	1	0100	1001	MDDD	DDDD
ADDT	Add to accumulator with shift specified by T register	1	0100	1010	MDDD	DDDD
ADLK	Add to accumulator long immediate with shift	2	1101	SSSS	0000	0010
AND	AND with accumulator	1	0100	1110	MDDD	DDDD
ANDK	AND immediate with accumulator with shift	2	1101	SSSS	0000	0100
CMPL	Complement accumulator	1	1100	1110	0010	0111
LAC	Load accumulator with shift	1	0010	SSSS	MDDD	DDDD
LACK	Load accumulator short immediate	1	1100	1010	KKKK	KKKK
LACT	Load accumulator with shift specified by T register	1	0100	0010	MDDD	DDDD
LALK	Load accumulator long immediate with shift	2	1101	SSSS	0000	0001
NEG	Negate accumulator	1	1100	1110	0010	0011
NORM	Normalize contents of accumulator	1	1100	1110	1010	0010
OR	OR with accumulator	1	0100	1101	MDDD	DDDD
ORK	OR immediate with accumulator with shift	2	1101	SSSS	0000	0101
ROL	Rotate accumulator left	1	1100	1110	0011	0100
ROR	Rotate accumulator right	1	1100	1110	0011	0101
SAC	Store high accumulator with shift	1	0110	1XXX	MDDD	DDDD
SACL	Store low accumulator with shift	1	0110	0XXX	MDDD	DDDD
SBLK	Subtract from accumulator long immediate with shift	2	1101	SSSS	0000	0011
SFL	Shift accumulator left	1	1100	1110	0001	1000
SFR	Shift accumulator right	1	1100	1110	0001	1001
SUB	Subtract from accumulator with shift	1	0001	SSSS	MDDD	DDDD
SUBB	Subtract from accumulator with borrow	1	0100	1111	MDDD	DDDD
SUBC	Conditional subtract	1	0100	0111	MDDD	DDDD
SUBH	Subtract from high accumulator	1	0100	0100	MDDD	DDDD
SUBK	Subtract from accumulator short immediate	1	1100	1101	KKKK	KKKK
SUBS	Subtract from low accumulator with sign extension suppressed		0100	0101	MDDD	DDDD
SUBT	Subtract from accumulator with shift specified by T register	1	0100	0110	MDDD	DDDD
XOR	Exclusive-OR with accumulator	1	0100	1100	MDDD	DDDD
XORK	Exclusive-OR immediate with accumulator with shift	2	1101	SSSS	0000	0110
ZAC	Zero accumulator	1	1100	1010	0000	0000
ZALH	Zero low accumulator and load high accumulator	1	0100	0000	MDDD	DDDD
ZALR	Zero low accumulator and load high accumulator with rounding	1	0111	1011	MDDD	DDDD
ZALS	Zero accumulator and load low accumulator with sign extension suppressed	1	0100	0001	MDDD	DDDD

Table 4–4. Instruction Set Summary (Continued)

AUXILIARY REGISTERS AND DATA PAGE POINTER INSTRUCTIONS						
Mnemonic and Description		**Words**	**16-Bit Opcode**			
			MSB			**LSB**
ADRK	Add to auxiliary register short immediate	1	0111	1110	KKKK	KKKK
CMPR	Compare auxiliary register with auxiliary register AR0	1	1100	1110	0101	00KK
LAR	Load auxiliary register	1	0011	0RRR	MDDD	DDDD
LARK	Load auxiliary register short immediate	1	1100	0RRR	KKKK	KKKK
LARP	Load auxiliary register pointer	1	0101	0101	1000	1RRR
LDP	Load data memory page pointer	1	0101	0010	MDDD	DDDD
LDPK	Load data memory page pointer immediate	1	1100	100K	KKKK	KKKK
LRLK	Load auxiliary register long immediate	2	1101	0RRR	0000	0000
MAR	Modify auxiliary register	1	0101	0101	MDDD	DDDD
SAR	Store auxiliary register	1	0111	0RRR	MDDD	DDDD
SBRK	Subtract from auxiliary register short immediate	1	0111	1111	KKKK	KKKK
T REGISTER, P REGISTER, AND MULTIPLY INSTRUCTIONS						
Mnemonic and Description		**Words**	**16-Bit Opcode**			
			MSB			**LSB**
APAC	Add P register to accumulator	1	1100	1110	0001	0101
LPH	Load high P register	1	0101	0011	MDDD	DDDD
LT	Load T register	1	0011	1100	MDDD	DDDD
LTA	Load T register and accumulate previous product	1	0011	1101	MDDD	DDDD
LTD	Load T register, accumulate previous product and move data	1	0011	1111	MDDD	DDDD
LTP	Load T register and store P register in accumulator	1	0011	1110	MDDD	DDDD
LTS	Load T register and subtract previous product	1	0101	1011	MDDD	DDDD
MAC	Multiply and accumulate	2	0101	1101	MDDD	DDDD
MACD	Multiply and accumulate with data move	2	0101	1100	MDDD	DDDD
MPY	Multiply (with T register, store product in P register)	1	0011	1000	MDDD	DDDD
MPYA	Multiply and accumulate previous product	1	0011	1010	MDDD	DDDD
MPYK	Multiply immediate	1	101K	KKKK	KKKK	KKKK
MPYS	Multiply and subtract previous product	1	0011	1011	MDDD	DDDD
MPYU	Multiply unsigned	1	1100	1111	MDDD	DDDD
PAC	Load accumulator with P register	1	1100	1110	0001	0100
SPAC	Subtract P register from accumulator	1	1100	1110	0001	0110
SPH	Store high P register	1	0111	1101	MDDD	DDDD
SPL	Store low P register	1	0111	1100	MDDD	DDDD
SPM	Set P register output shift mode	1	1100	1110	0000	10KK
SQRA	Square and accumulate	1	0011	1001	MDDD	DDDD
SQRS	Square and subtract previous product	1	0101	1010	MDDD	DDDD

Table 4–4. Instruction Set Summary (Continued)

BRANCH/CALL INSTRUCTIONS						
Mnemonic and Description		**Words**	**16-Bit Opcode**			
			MSB			**LSB**
I/O AND DATA MEMORY OPERATIONS						
B	Branch unconditionally	2	1111	1111	1DDD	DDDD
BACC	Branch to address specified by accumulator	1	1100	1110	0010	0101
BANZ	Branch on auxiliary register not zero	2	1111	1011	1DDD	DDDD
BBNZ	Branch if TC bit ≠ 0	2	1111	1001	1DDD	DDDD
BBZ	Branch if TC bit = 0	2	1111	1000	1DDD	DDDD
BC	Branch on carry	2	0101	1110	1DDD	DDDD
BGEZ	Branch if accumulator ≠ 0	2	1111	0100	1DDD	DDDD
BGZ	Branch if accumulator > 0	2	1111	0001	1DDD	DDDD
BIOZ	Branch on I/O status = 0	2	1111	1010	1DDD	DDDD
BLEZ	Branch if accumulator ≤ 0	2	1111	0010	1DDD	DDDD
BLZ	Branch if accumulator < 0	2	1111	0011	1DDD	DDDD
BNC	Branch on no carry	2	0101	1111	1DDD	DDDD
BNV	Branch if no overflow	2	1111	0111	1DDD	DDDD
BNZ	Branch if accumulator ≠ 0	2	1111	0101	1DDD	DDDD
BV	Branch on overflow	2	1111	0000	1DDD	DDDD
BZ	Branch if accumulator = 0	2	1111	0110	1DDD	DDDD
CALA	Call subroutine indirect	1	1100	1110	0010	0100
CALL	Call subroutine	2	1111	1110	1DDD	DDDD
RET	Return from subroutine	1	1100	1110	0010	0110
TRAP	Software interrupt	1	1100	1110	0001	1110
I/O AND DATA MEMORY OPERATIONS						
Mnemonic and Description		**Words**	**16-Bit Opcode**			
			MSB			**LSB**
BLKD	Block move from data memory to data memory	2	1111	1101	MDDD	DDDD
BLKP	Block move from program memory to data memory	2	1111	1100	MDDD	DDDD
DMOV	Data move in data memory	1	0101	0110	MDDD	DDDD
FORT	Format serial port registers	1	1100	1110	0000	111K
IN	Input data from port	1	1000	AAAA	MDDD	DDDD
OUT	Output data to port	1	1110	AAAA	MDDD	DDDD
RFSM	Reset serial port frame synchronization mode	1	1100	1110	0011	0110
RTXM	Reset serial port transmit mode	1	1100	1110	0010	0000
RXF	Reset external flag	1	1100	1110	0000	1100
SFSM	Set serial port frame synchronization mode	1	1100	1110	0011	0111
STXM	Set serial port transmit mode	1	1100	1110	0010	0001
SXF	Set external flag	1	1100	1110	0000	1101
TBLR	Table read	1	0100	1000	MDDD	DDDD
TBLW	Table write	1	0101	1001	MDDD	DDDD

Table 4–4. Instruction Set Summary (Continued)

CONTROL INSTRUCTIONS						
Mnemonic and Description		**Words**	**16-Bit Opcode**			
			MSB			**LSB**
BIT	Test bit	1	1001	BBBB	MDDD	DDDD
BITT	Test bit specified by T register	1	0101	0111	MDDD	DDDD
CNFD†	Configure block as data memory	1	1100	1110	0000	0100
CNFP†	Configure block as program memory	1	1100	1110	0000	0101
CONF†	Configure block as data/program memory	1	1100	1110	0011	11KK
DINT	Disable interrupt	1	1100	1110	0000	0001
EINT	Enable interrupt	1	1100	1110	0000	0000
IDLE	Idle until interrupt	1	1100	1110	0001	1111
LST	Load status register ST0	1	0101	0000	MDDD	DDDD
LST1	Load status register ST1	1	0101	0001	MDDD	DDDD
NOP	No operation	1	0101	0101	0000	0000
POP	Pop top of stack to low accumulator	1	1100	1110	0001	1101
POPD	Pop top of stack to data memory	1	0111	1010	MDDD	DDDD
PSHD	Push data memory value onto stack	1	0101	0100	MDDD	DDDD
PUSH	Push low accumulator onto stack	1	1100	1110	0001	1100
RC	Reset carry bit	1	1100	1110	0011	0000
RHM	Reset hold mode	1	1100	1110	0011	1000
ROVM	Reset overflow mode	1	1100	1110	0000	0010
RPT	Repeat instruction as specified by data memory value	1	0100	1011	MDDD	DDDD
RPTK	Repeat instruction as specified by immediate value	1	1100	1011	KKKK	KKKK
RSXM	Reset sign-extension mode	1	1100	1110	0000	0110
RTC	Reset test/control flag	1	1100	1110	0011	0010
SC	Set carry bit	1	1100	1110	0011	0001
SHM	Set hold mode	1	1100	1110	0011	1001
SOVM	Set overflow mode	1	1100	1110	0000	0011
SST	Store status register ST0	1	0111	1000	MDDD	DDDD
SST1	Store status register ST1	1	0111	1001	MDDD	DDDD
SSXM	Set sign-extension mode	1	1100	1110	0000	0111
STC	Set test/control flag	1	1100	1110	0011	0011

†) The CONF instruction is specific to the TMS320C26 instruction set; the instructions CNFD and CNFP are undefined.

4.3 Individual Instruction Descriptions

Each instruction in the instruction set summary is described in the following pages. Instructions are listed in alphabetical order. Information, such as assembler syntax, operands, operation, encoding, description, words, cycles, and examples, is provided for each instruction. An example instruction is provided to familiarize you with the special format used and to explain its content. Refer to Section 4.1 for further information on memory addressing. Code examples using many of the instructions are given in Chapter 5, *Software Application*s.

Syntax

Direct:	[*label*]	EXAMPLE	*dma* [, *shift*]
Indirect:	[*label*]	EXAMPLE	{ind} [, *shift* [*next ARP*]]
Immediate:	[*label*]	EXAMPLE	[*constant*]

Each instruction begins with an assembler syntax expression. The optional comment field that concludes the syntax is not included in the syntax expression. Space(s) are required between each field (label, command, operand, and comment fields) as shown in the syntax. The syntax example illustrates both direct and indirect addressing, as well as immediate addressing in which the operand field includes *constant*.

The indirect addressing operand options, including bit-reversed (BR) addressing, are as follows:

TMS320C25: { * | * + | * – | * 0 + | * 0 – | * BRO + | * BRO –}

Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7
$0 \leq$ constant ≤ 255

Operands may be constants or assembly-time expressions referring to memory, I/O and register addresses, pointers, shift counts, and a variety of constants. The operand values used in the example syntax are shown.

Execution

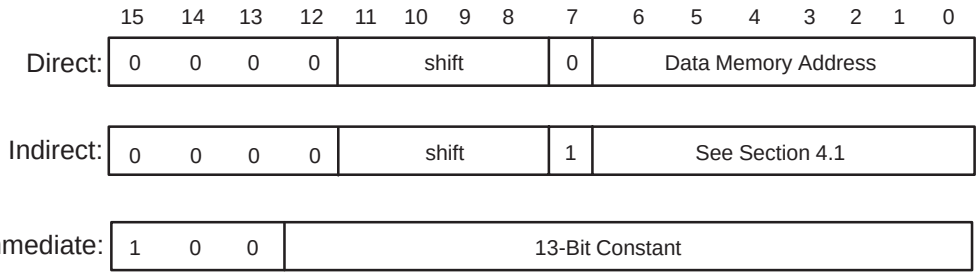
$(PC) + 1 \rightarrow PC$
$(ACC) + [(dma) \times 2^{shift}] \rightarrow ACC$

If SXM = 1:
  Then (dma) is sign-extended.
If SXM = 0:
  Then (dma) is not sign-extended.

Affects OV; affected by OVM and SXM.
Affects C.

An example of the instruction operation sequence is provided, describing the processing that takes place when the instruction is executed. Conditional effects of status register specified modes are also given. Those bits in the TMS320C2x status registers affected by the instruction are also listed.

Encoding



Opcode examples are shown of both direct and indirect addressing or of the use of an immediate operand.

Description

Instruction execution and its effect on the rest of the processor or memory contents are described. Any constraints on the operands imposed by the processor or the assembler are discussed. The description parallels and supplements the information given by the execution block.

Words

1

The digit specifies the number of memory words required to store the instruction and its extension words.

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

The table shows the number of cycles required for a given TMS320C2x instruction to execute in a given memory configuration when executed as a single instruction or in the repeat mode. The column headings in the tables indicate the program source location (PI, PE, or PR) and data destination or source (DI or DE), defined as follows:

PI The instruction executes from internal program memory (RAM).

PR The instruction executes from internal program memory (ROM).

PE The instruction executes from external program memory.

DI The instruction executes using internal data memory.

DE The instruction executes using external data memory.

The number of cycles required for each instruction is given in terms of the program/data memory and I/O access times as defined in the following listing:

p Program memory wait states. Represents the number of clock cycles the device waits for external program memory to respond to an access. T_{ac} is the access time, in nanoseconds, (maximum) required by the TMS320C2x for an external memory access to be made with no wait states. T_{mem} is the memory device access time, and T_p is the clock period (4/crystal frequency).

$p = 0$; If $T_{mem} \leq T_{ac}$

$p = 1$; If $T_{ac} < T_{mem} \leq (T_p + T_{ac})$

$p = 2$; If $(T_p + T_{ac}) < T_{mem} \leq (T_p \times 2 + T_{ac})$

$p = k$; If $[T_p \times (k–1) + T_{ac}] < T_{mem} \leq (T_p \times k + T_{ac})$

d Data memory wait states. Represents the number of cycles the device must wait for external data memory to respond to an access. This number is calculated in the same way as the p number.

i I/O memory wait states. Represents the number of cycles the device must wait for external I/O memory to respond to an access. This number is calculated in the same way as the p number.

Other abbreviations used in the tables and their meanings are as follows:

br Branch from ...

int Internal program memory.

INT Interrupt.

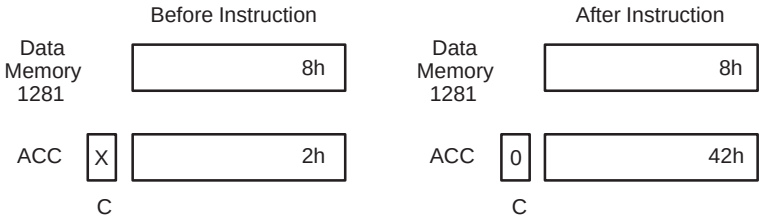
ext External program memory.

n The number of times an instruction is executed when using the RPT or RPTK instruction.

Refer to Appendix D for further information on instruction cycle classifications and timings.

Example

```
ADD   DAT1,3   ;(DP = 10)
 or
ADD   *,3      ;If current auxiliary register contains 1281.
```



The sample code presented in the above format shows the effect of the code on memory and/or registers. The use of the carry bit (C) provided on the TMS320C25 is shown in the small box.

Syntax [*label*] ABS

Operands None

Execution

(PC) + 1 → PC
|(ACC)| → ACC

Affects OV; affected by OVM.
Affects C.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	1

Description

If the contents of the accumulator are greater than or equal to zero, the accumulator is unchanged by the execution of ABS. If the contents of the accumulator are less than zero, the accumulator is replaced by its 2s-complement value.

Note that 80000000h is a special case. When the overflow mode is not set, the ABS of 80000000h is 80000000h. In the overflow mode, the ABS of 80000000h is 7FFFFFFFh. In either case, the OV status bit is set. The carry bit (C) on the TMS320C2x is always reset to zero by the execution of this instruction.

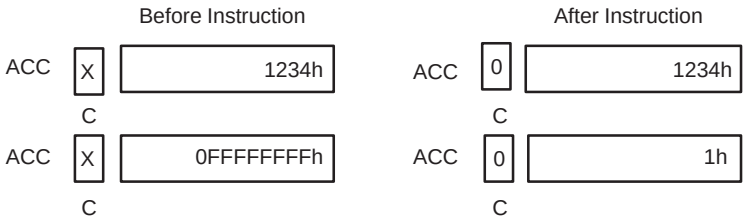
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

ABS


Before Instruction
After Instruction
ACC
X
1234h
C
ACC
0
1234h
C
ACC
X
0FFFFFFFFh
C
ACC
0
1h
C

Syntax

Direct: [*label*] ADD *dma*[, *shift*]
Indirect: [*label*] ADD {ind} [, *shift* [, *next ARP*]]

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ shift ≤ 15 (defaults to 0)

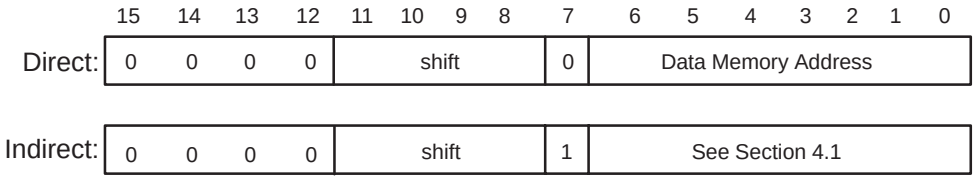
Execution

(PC) + 1 $\rightarrow$ PC
(ACC) + [(dma) x 2^{shift}] $\rightarrow$ ACC

If SXM = 1:
Then (dma) is sign-extended.
If SXM = 0:
Then (dma) is not sign-extended.

Affects OV; affected by OVM and SXM.
Affects C.

Encoding



Description

The contents of the addressed data memory location are left- shifted and added to the accumulator. During shifting, low-order bits are zero-filled. High-order bits are sign-extended if SXM = 1 and zero-filled if SXM = 0. The result is stored in the accumulator.

Words

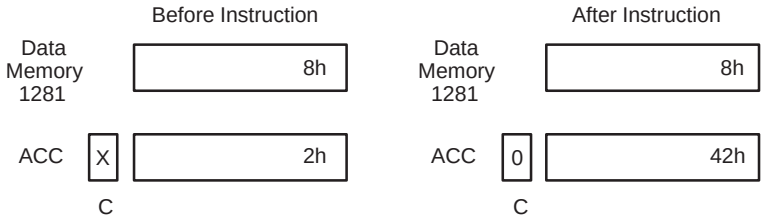
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ADD DAT1,3     ;(DP = 10)
or
ADD *,3        ;If current auxiliary register contains 1281.
```



Syntax

Direct: [*label*] ADDC *dma*
Indirect: [*label*] ADDC {ind} [, *next ARP*]

Operands

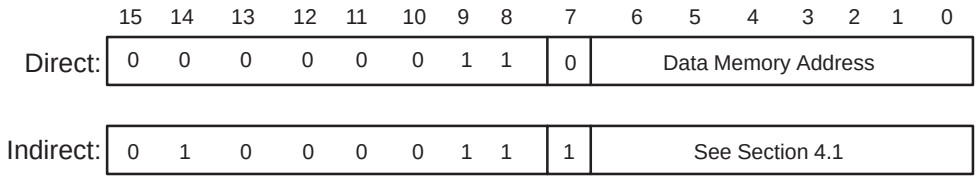
$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(ACC) + (dma) + (C) $\rightarrow$ ACC

Affects OV and C; affected by OVM.

Encoding



Description

The contents of the addressed data memory location and the value of the carry bit are added to the accumulator. The carry bit is then affected in the normal manner.

The ADDC instruction can be used in performing multiple-precision arithmetic.

Words

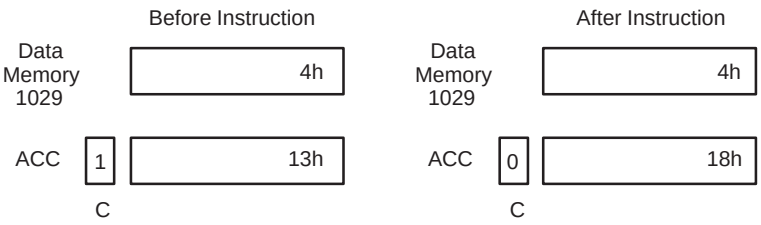
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

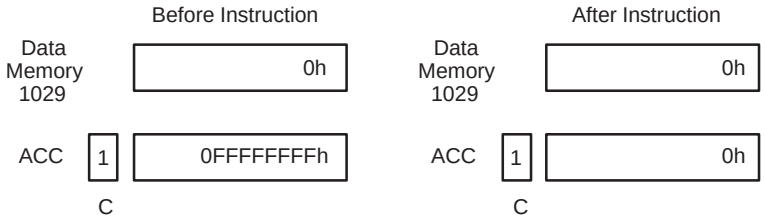
Example 1

```
ADDC DAT5       ;(DP = 8)
```
or
```
ADDC *          ;If current auxiliary register contains 1029.
```



Example 2

```
ADDC DAT5      ;(DP = 8)
or
ADDC *         ;If current auxiliary register contains 1029.
```



Syntax

Direct: [*label*] ADDH *dma*
Indirect: [*label*] ADDH {ind} [, *next ARP*]

Operands

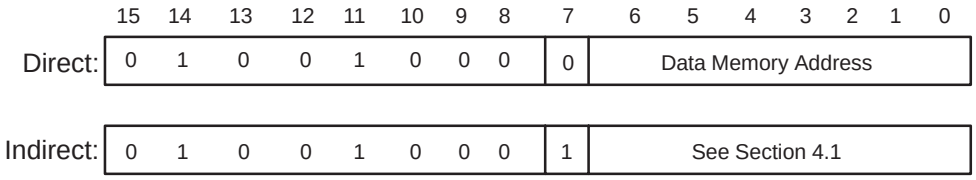
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(ACC) + [(dma) $\times 2^{16}$] $\rightarrow$ ACC

Affects OV; affected by OVM.
Affects C.
Low-order bits of the ACC not affected.

Encoding



Description

The contents of the addressed data memory location are added to the upper half of the accumulator (bits 31 through 16). Low-order bits are unaffected by ADDH. The carry bit (C) on the TMS320C2x is set if the result of the addition generates a carry; otherwise, C is unaffected. The carry bit can only be set, not reset, by the ADDH instruction.

The ADDH instruction may be used in performing 32-bit arithmetic.

Words

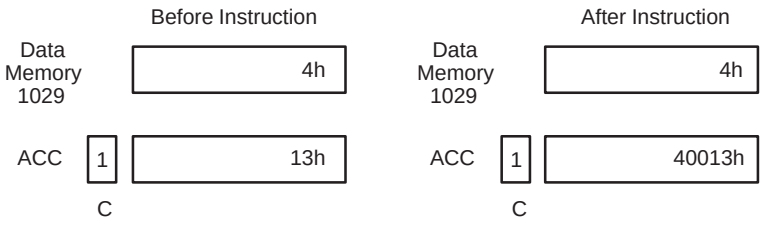
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ADDH DAT5      ;(DP = 8)
or
ADDH *         ;If current auxiliary register contains 1029.
```



Syntax [*label*] ADDK *constant*

Operands 0 ≤ constant ≤ 255

Execution
(PC) + 1 → PC
(ACC) + 8-bit positive constant → ACC

Affects OVM and C; affected by OVM.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	0	0	8-Bit constant							

Description The 8-bit immediate value is added, right-justified, to the accumulator with the result replacing the accumulator contents. The immediate value is treated as an 8-bit positive number, regardless of the value of SXM.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1 + p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
ADDK 5h
```

ADDS *Add to Accumulator With Sign-Extension Suppressed*

Syntax

Direct: [*label*] ADDS *dma*
Indirect: [*label*] ADDS {ind}[, *next ARP*]

Operands

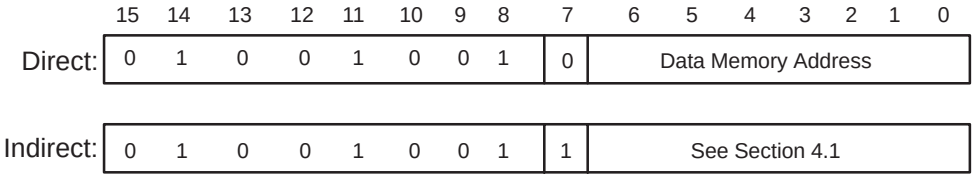
$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(ACC) + (dma) $\rightarrow$ ACC
(dma) is a 16-bit unsigned number.

Affects OV; affected by OVM.
Affects C.
Not affected by SXM.

Encoding



Description

The contents of the specified data memory location are added with sign-extension suppressed. The data is treated as a 16-bit unsigned number, regardless of SXM. The accumulator behaves as a signed number. Note that ADDS produces the same results as an ADD instruction with SXM = 0 and a shift count of 0.

Words

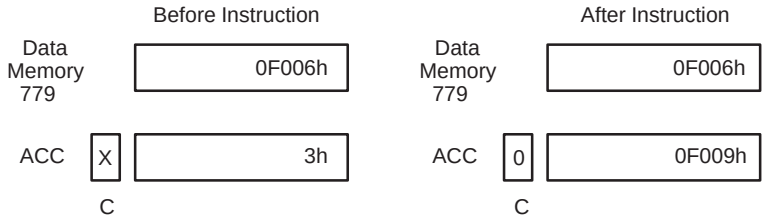
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ADDS DAT11      ;(DP = 6)
or
ADDS *          ;If current auxiliary register contains 779.
```



Syntax

Direct: [*label*] ADDT *dma*
Indirect: [*label*] ADDT {ind} [, *next ARP*]

Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC

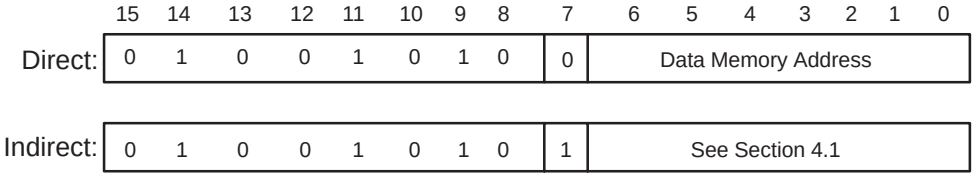
(ACC) + [(dma) $\times 2^{\text{T register(3–0)}}$] $\rightarrow$ (ACC)

If SXM = 1:
Then (dma) is sign-extended.

If SXM = 0:
Then (dma) is not sign-extended.

Affects OV; affected by SXM and OVM.
Affects C.

Encoding



Description

The data memory value is left- shifted and added to the accumulator, with the result replacing the accumulator contents. The left- shift is defined by the four LSBs of the T register, resulting in shift options from 0 to 15 bits. Sign extension on the data memory value is controlled by SXM.

Words

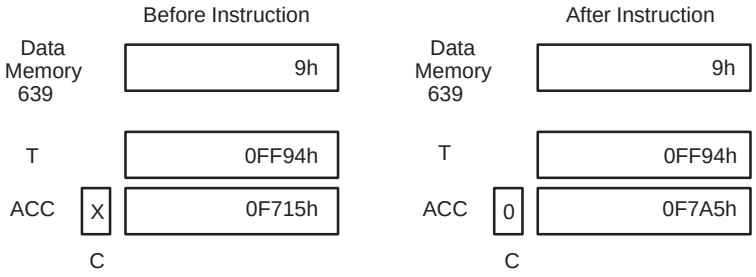
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ADDT DAT127    ;(DP = 4)
or
ADDT *         ;If current auxiliary register contains 639.
```



Syntax [*label*] ADLK *constant* [, *shift*]

Operands
16-bit constant
0 ≤ shift ≤ 15 (defaults to 0)

Execution
(PC) + 2 → PC
(ACC) + [constant x 2^{shift}] → ACC

If SXM = 1:
Then –32768 ≤ constant ≤ 32767.
If SXM = 0:
Then 0 ≤ constant ≤ 65535.

Affects OV; affected by OVM and SXM.
Affects C.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	shift				0	0	0	0	0	0	1	0
16-Bit Constant															

Description
The 16-bit immediate value, left- shifted as specified, is added to the accumulator. The result replaces the accumulator contents. SXM determines whether the constant is treated as a signed 2s-complement number or as an unsigned number. The shift count is optional and defaults to zero.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
ADLK 5,8
```

Syntax [*label*] ADRK *constant*

Operands $0 \leq$ constant ≤ 255

Execution (PC) + 1 → PC
AR(ARP) + 8-bit positive constant → AR(ARP)

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	0	1	1	1	1	1	1	0	8-Bit constant							

Description The 8-bit immediate value is added, right-justified, to the currently selected auxiliary register with the result replacing the auxiliary register contents. The addition takes place in the ARAU, with the immediate value treated as an 8-bit positive integer.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1 + p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
ADRK 80h        ;(ARP = 5)
```

	Before Instruction		After Instruction
AR5	4321h	AR5	43A1h

Syntax

Direct: [*label*] AND *dma*
Indirect: [*label*] AND {ind} [, *next ARP*]

Operands

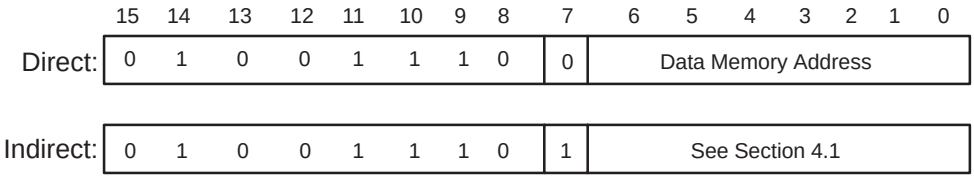
$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(ACC(15–0)) AND (dma) $\rightarrow$ ACC(15–0)
0 $\rightarrow$ ACC(31–16)

Not affected by SXM.

Encoding



Description

The lower half of the accumulator is ANDed with the contents of the addressed data memory location. The upper half of the accumulator is ANDed with all zeroes. Therefore, the upper half of the accumulator is always zeroed by the AND instruction.

Words

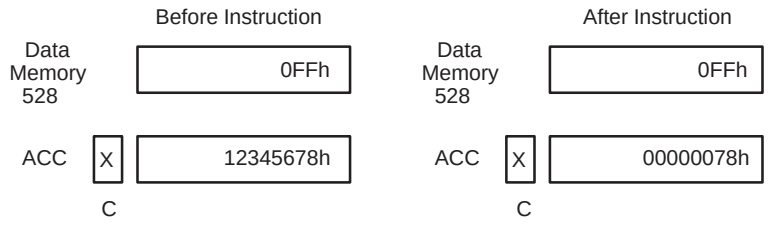
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
AND DAT16      ;(DP = 4)
or
AND *          ;If current auxiliary register contains 528.
```



Syntax [*label*] ANDK *constant* [, *shift*]

Operands 16-bit constant
$0 \le$ shift ≤ 15 (defaults to 0)

Execution (PC) + 2 $\rightarrow$ PC
(ACC(30–0)) AND [(constant $\times$ 2^{shift})] $\rightarrow$ ACC(30–0)
0 $\rightarrow$ ACC(31) and all other bit positions unoccupied by shifted constant.

Not affected by SXM.

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	1	1	0	1	shift				0	0	0	0	0	1	0	0
Indirect:	16-Bit constant															

Description The 16-bit immediate constant is left-shifted as specified and ANDed with the accumulator. The result is left in the accumulator. Low-order bits below and high-order bits above the shifted value are treated as zeros, clearing the corresponding bits in the accumulator. Note that the accumulator's most-significant bit is always zeroed regardless of the shift-code value.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
ANDK  0FFFFh,12
```

Syntax

[*label*] APAC

Operands

None

Execution

(PC) + 1 → PC
(ACC) + (shifted P register) → ACC

Affects OV; affected by PM and OVM.
Affects C.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	0	1	0	1

Description

The contents of the P register are shifted as defined by the PM status bits and added to the contents of the accumulator. The result is left in the accumulator. APAC is not affected by the SXM bit of the status register; the P register is always sign-extended.

The APAC instruction is a subset of the LTA, LTD, MAC, MACD, MPYA, and SQRA instructions.

Words

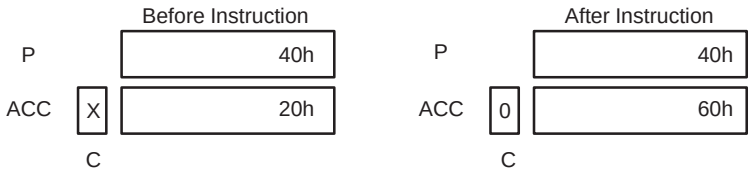
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
APAC            ;(PM = 0)
```



Syntax [*label*] B *pma* [,{ind} [, *next ARP*]]

Operands $0 \leq$ pma ≤ 65535
$0 \leq$ next ARP ≤ 7

Execution pma $\rightarrow$ PC
Modify AR(ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	1	1	1	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified, and control passes to the designated program memory address (pma). Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
B     PRG191   ;191 is loaded into the program counter,
               ;and the program continues running from
               ;that location.
```

Syntax [*label*] BACC

Operands None

Execution (ACC(15–0)) → PC

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	0	0	1	0	1

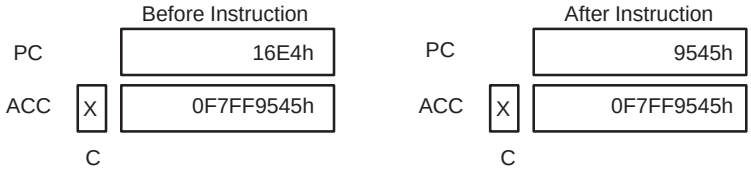
Description The branch uses the lower half of the accumulator (bits 15 – 0) for the branch address.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Destination on-chip RAM:					
2	2	2+p	2+p	2	2
Destination on-chip ROM:					
3	3	3+p	3+p	3	3
Destination external memory:					
3+p	3+p	3+2p	3+2p	3+p	3+p
Cycle Timings for a Repeat Execution					
not repeatable					

Example BACC



Syntax

[*label*] BANZ *pma* [,{ind} [, *next ARP*]]

Operands

$0 \le$ pma ≤ 65535
$0 \le$ next ARP ≤ 7

Execution

If AR (ARP) $\neq 0$:
  Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
  Modify AR (ARP) as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	0	1	1	1	See Section 4.1						
Program Memory Address															

Description

Control is passed to the designated program memory address (pma) if the current auxiliary register is not equal to zero. Otherwise, control passes to the next instruction. The current auxiliary register and ARP are also modified as specified.

Description

The current auxiliary register is either incremented or decremented from zero when the branch is not taken. Note that the AR modification defaults to *- (decrement current AR by one) when nothing is specified, making it compatible with the TMS320C1x. The pma can be either a symbolic or a numeric address.

Words

2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example 1

```
BANZ  PRG35, * –
```

	Before Instruction		After Instruction	
	AR	1h	AR	0h
	PC	46h	PC	35h
or				
	AR	0h	AR	0FFFFh
	PC	46h	PC	48h

Example 2

```
BANZ  PRG64, * +
```

	Before Instruction		After Instruction	
	AR	0FFFFh	AR	0h
	PC	117h	PC	64h
or				
	AR	0h	AR	1h
	PC	117h	PC	119h

Note:

BANZ is designed for loop control using the auxiliary registers as loop counters. Using *0 + or *0 – allows modification of the loop counter by a variable step size. Care must be exercised when doing this, however, because the auxiliary registers behave as modulo 65536 counters, and zero may be passed without being detected if ARO > 1.

Syntax [*label*] BBNZ *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65536
$0 \le$ next ARP ≤ 7

Execution
If test/control (TC) status = 1:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR (ARP) and ARP as specified.

Affected by TC bit

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	0	0	1	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address if TC = 1. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or numeric address. Note that the TC bit may be affected by the BIT, BITT, CMPR, LST1, NORM, RTC, and STC instructions.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BBNZ  PRG650   ;If TC = 1, 650 is loaded into the program
               ;counter ; otherwise, the program counter
               ;is incremented by 2.
```

Syntax [*label*] BBZ *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65536
$0 \le$ next ARP ≤ 7

Execution
If test/control (TC) status bit = 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR (ARP) and ARP as specified.

Affected by TC bit

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	0	0	0	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address if TC = 0. Otherwise, control passes to the next instruction. No AR or ARP modification occurrs if nothing is speciified in those fields. The pma can be either a symbolic or a numeric address. Note that the TC bit is affected by the BIT, BITT, CMPR, LST1, NORM, RTC, and STC instructions.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BBZ PRG325     ;If TC = 0, 325 is loaded into the program
               ;counter; otherwise, the program counter
               ;is incremented by 2.
```

Syntax [*label*] BC *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le pma \le 65536$
$0 \le next\ ARP \le 7$

Execution
If carry bit C = 1:
Then pma → PC;
Else (PC) + 2 → PC.
Modify AR (ARP) and ARP as specified.

Affected by TC bit

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	1	0	1	1	1	1	0	1	See Section 4.1						
Program Memory Address															

Description
The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address if the carry bit C is high. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Note that the carry bit C is affected by all add, subtract, and accumulate instructions as well as the ABS, LST1, NEG, RC, SC, rotate, and shift instructions. The carry bit is not affected by execution of BC, BNC, or nonarithmetic instructions.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BC    PRG512   ;If the carry bit C = 1, 512 is loaded into the
               ;program counter. Otherwise, the PC is
               ;incremented by 2.
```

Syntax [*label*] BGEZ *pma* [, {ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65536
$0 \le$ next ARP ≤ 7

Execution
If (ACC) ≥ 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR (ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	0	1	0	0	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the contents of the accumulator are greater than or equal to zero. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BGEZ  PRG217   ;217 is loaded into the program counter if the
               ;accumulator is greater than or equal to zero.
```

Syntax [*label*] BGZ *pma* [, {ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65536
$0 \le$ next ARP ≤ 7

Execution
If (ACC) > 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR (ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	0	0	0	1	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the contents of the accumulator are greater than zero. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BGZ   PRG342   ;342 is loaded into the program counter if the
               ;accumulator is greater than or equal to zero.
```

Syntax [*label*] BIOZ *pma* [, {ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65536
$0 \le$ next ARP ≤ 7

Execution
If $\overline{\text{BIO}}$ = 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR (ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	0	1	0	1	See Section 4.1						
Program Memory Address															

Description
The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the $\overline{\text{BIO}}$ pin is low. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

BIOZ in conjunction with the $\overline{\text{BIO}}$ pin can be used to test if a peripheral is ready to send or receive data. Polling the $\overline{\text{BIO}}$ pin by using BIOZ may be preferable to an interrupt when executing time-critical loops.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BIOZ  PRG64    ;If the BIO pin is active (low), then a branch
               ;to location 64 occurs.
```

Syntax

Direct: [*label*] BIT *dma* , *bit code*
Indirect : [*label*] BIT {ind} , *bit code* [, *next ARP*]

Operands

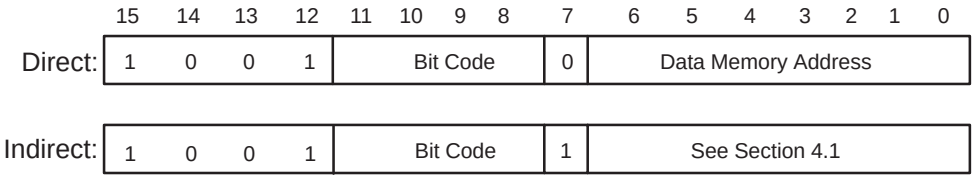
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ bit code ≤ 15

Execution

(PC) + $\rightarrow$ PC
(dma bit at bit address (15-bit code)) $\rightarrow$ TC.

Affects TC.

Encoding



Description

The BIT instruction copies the specified bit of the data memory value to the TC bit of status register ST1. Note that the BITT, CMPR, LST1, and NORM instructions also affect the TC bit in status register ST1. A bit code value is specified that corresponds to a certain bit address in the instruction, as given by the following table:

Bit Address		Bit Code			
		11	10	9	8
(LSB)	0	1	1	1	1
	1	1	1	1	0
	2	1	1	0	1
	3	1	1	0	0
	4	1	0	1	1
	5	1	0	1	0
	6	1	0	0	1
	7	1	0	0	0
	8	0	1	1	1
	9	0	1	1	0
	10	0	1	0	1
	11	0	1	0	0
	12	0	0	1	1
	13	0	0	1	0
	14	0	0	0	1
(MSB)	15	0	0	0	0

Words

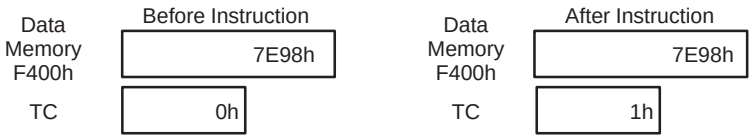
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
BIT   0h, 8h   ;(DP = 488)
or
BIT   *,8      ;If current auxiliary register contains 0F400h.
```



Syntax

Direct: [*label*] BITT *dma*
Indirect: [*label*] BITT {ind} [, *next ARP*]

Operands

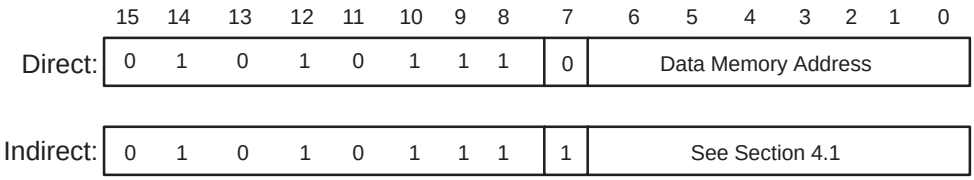
$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma bit at bit address (15–T register(3–0))) → TC

Affects TC.

Encoding



Description

The BITT instruction copies the specified bit of the data memory value to the TC bit of status register ST1. Note that the BIT, CMPR, LST1, and NORM instructions also affect the TC bit in status register ST1. The bit address is specified by a bit code value contained in the LSBs of the T register, as given in the following table:

Bit Code

Bit Address	3 2 1 0
(LSB) 0	1 1 1 1
1	1 1 1 0
2	1 1 0 1
3	1 1 0 0
4	1 0 1 1
5	1 0 1 0
6	1 0 0 1
7	1 0 0 0
8	0 1 1 1
9	0 1 1 0
10	0 1 0 1
11	0 1 0 0
12	0 0 1 1
13	0 0 1 0
14	0 0 0 1
(MSB) 15	0 0 0 0

Words

1

Cycles

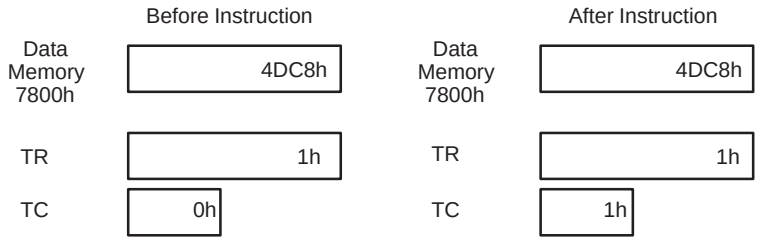
Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
BITT  0h      ;Value in T register points to bit 14 of
              ;data word (DP = 240).
```

or

```
BITT  *       ;If current auxiliary register contains 7800h.
```



Syntax [*label*] BLEZ *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65535
$0 \le$ next ARP ≤ 7

Execution
If (ACC) ≤ 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR(ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	0	0	1	0	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the contents of the accumulator are less than or equal to zero. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BLEZ  PRG63    ;63 is loaded into the program counter if the
               ;accumulator is less than or equal to zero.
```

Syntax

Direct: [*label*] BLKD *dma1* , *dma2*
Indirect: [*label*] BLKD *dma1* ,{ind} [, *next ARP*]

Operands

$0 \leq$ dma1 ≤ 65535
$0 \leq$ dma2 ≤ 127
$0 \leq$ next $\leq$ ARP ≤ 7

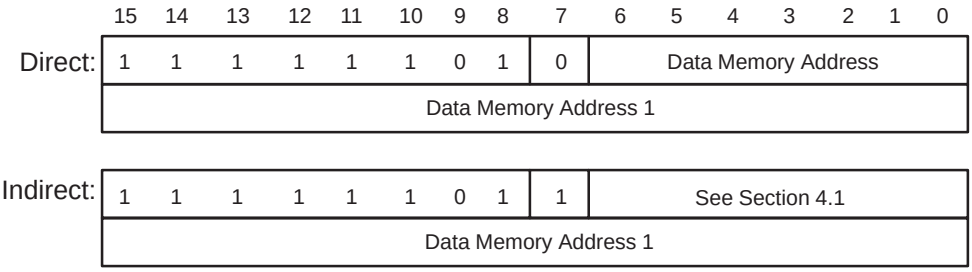
Execution

(PC) + 2 $\rightarrow$ PC
(PFC) $\rightarrow$ MCS
dma1 $\rightarrow$ PFC

If (repeat counter) $\neq 0$:
Then (dma1, addressed by PFC) $\rightarrow$ dma2,
Modify AR(ARP) and ARP as specified,
(PFC) + 1 $\rightarrow$ PFC,
(repeat counter) – 1 $\rightarrow$ repeat counter.

Else (dma1, addressed by PFC) $\rightarrow$ dma2
Modify AR(ARP) and ARP as specified.
(MCS) $\rightarrow$ PFC

Encoding


15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Direct:
1 1 1 1 1 1 0 1 0 Data Memory Address
Data Memory Address 1
Indirect:
1 1 1 1 1 1 0 1 1 See Section 4.1
Data Memory Address 1

Description

Consecutive memory words are moved from a source data memory block to a destination data memory block. The starting address (lowest) of the source block is defined by the second word of the instruction. The starting address of the destination block is defined by either the dma contained in the opcode (for direct addressing) or the current AR (for indirect addressing). In the indirect addressing mode, both the current AR and ARP may be modified in the usual manner. In the direct addressing mode, dma2 is used as the destination address for the block move but is not modified upon repeated executions of the instruction. Thus, the contents of memory at the dma2 address will be the same as the contents of memory at the last dma1 address in a repeat sequence.

RPT or RPTK must be used with the BLKD instruction, in the indirect addressing mode, if more than one word is to be moved. The number of words to be moved is one greater than the number contained in the repeat counter RPTC at the beginning of the instruction. At the end of this instruction, the RPTC contains zero and, if using indirect addressing, AR(ARP) will be modified to contain the address after the end of the destination block. Note that the source and destination blocks do *not* have to be entirely on-chip or off-chip. However, BLKD cannot be used to transfer data from a memory-mapped register to any other location in data memory.

The PC points to the instruction following BLKD after execution. Interrupts are inhibited during a BLKD operation used with RPT or RPTK.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Source data in on-chip RAM:					
3	3+d	3+2p	3+d+2p	3	3+d
Source data in external memory:					
4+d	4+2d	4+d+2p	4+2d+2p	4+d	4+2d
Cycle Timings for a Repeat Execution					
Source data in on-chip RAM:					
2+n	2+n+nd	2+n+2p	2+n+nd+2p	2+n	2+n+nd
Source data in external memory:					
3+n+nd	2+n+ nd	3+n+nd+2p	2+2n+2nd+ 2p	3+n+nd	2+2n+2nd

Example

```
RPTK  2
BLKD  0F400h,*+ ;If current auxiliary register contains 1030.
```

dma1

	Before Instruction	After Instruction
Data Memory 62464	7F98h	7F98h
Data Memory 62465	0FFE6h	0FFE6h
Data Memory 62466	9522h	9522h

dma2

	Before Instruction	After Instruction
Data Memory 1030	7F98h	7F98h
Data Memory 1031	9315h	0FFE6h
Data Memory 1032	2531h	9522h

Syntax

Direct: [*label*] BLKP *pma*, *dma*
Indirect: [*label*] BLKP *pma*,{ind}[, *next ARP*]

Operands

$0 \le$ pma ≤ 65535
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

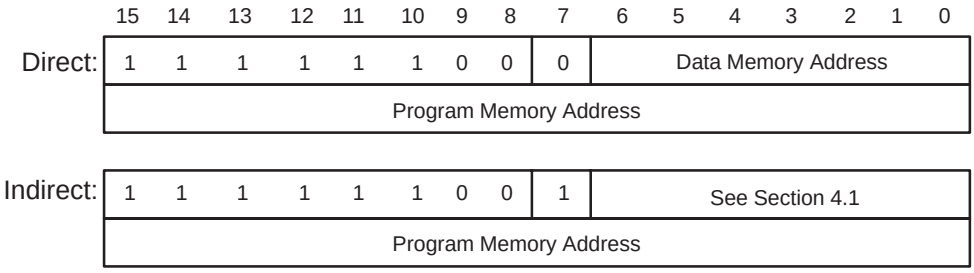
Execution

(PC) + 2 → PC
(PFC) → MCS
pma → PFC

If (repeat counter) ≠ 0:
Then (pma, addressed by PFC) → dma,
Modify AR(ARP) and ARP as specified,
(PFC) + 1 → PFC,
(repeat counter) – 1 → repeat counter.

Else (pma, addressed by PFC) → dma
Modify AR(ARP) and ARP as specified.
(MCS) → PFC

Encoding


15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Direct:
1 1 1 1 1 1 0 0 0
Data Memory Address
Program Memory Address
Indirect:
1 1 1 1 1 1 0 0 1
See Section 4.1
Program Memory Address

Description

Consecutive memory words are moved from a source program memory block to a destination data memory block. The starting address (lowest) of the source block is defined by the second word of the instruction. The starting address of the destination block is defined by either the dma contained in the opcode (for direct addressing) or the current AR (for indirect addressing). In the indirect addressing mode, both the ARP and the current AR may be modified in the usual manner. In the direct addressing mode, dma is used as the destination address for the block move but is not modified by repeated executions of the instruction. Thus, the contents of memory at the dma address will be the same as the contents of memory at the last pma address in a repeat sequence.

RPT or RPTK must be used with the BLKP instruction if more than one word is to be moved. The number of words to be moved is one greater than the number contained in the repeat counter RPTC at the beginning of the instruction. At the end of this instruction, the RPTC contains zero and, if using indirect addressing, AR(ARP) will be modified to contain the address after the end of the destination block. Note that source and destination blocks do *not* have to be entirely on-chip or off-chip.

The PC points to the instruction following BLKP after execution. Interrupts are inhibited during a BLKP operation.

If the MP/$\overline{MC}$ pin on the TMS320C25 is low at the time of execution of this instruction and the program memory address used is less than 4096, an on-chip ROM location will be read.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Table in on-chip RAM:					
3	3+d	4+2p	4+d+2p	4	4+d
Table in on-chip ROM:					
4	4+d	4+2p	4+d+2p	4	4+d
Table in external memory:					
4+p	4+d+p	4+3p	4+d+3p	4+p	4+d+p
Cycle Timings for a Repeat Execution					
Table in on-chip RAM:					
2+n	2+n+nd	2+n+2p	2+n+nd+2p	—	—
Table in on-chip ROM:					
3+n	3+n+nd	3+n+2p	3+n+nd+2p	3+n	3+n+nd
Table in external memory:					
3+n+np	2+2n+nd+np	3+n+np+2p	2+2n+nd+ np+2p	3+n+n p	2+2n+nd+np

Example

```
RPTK  2
BLKP  65120,*+ ;If current auxiliary register contains 2048.
```

pma

	Before Instruction	After Instruction
Data Memory 65120	0A089h	0A089h
Data Memory 65121	2DCEh	2DCEh
Data Memory 65122	3A9Fh	3A9Fh

dma

	Before Instruction	After Instruction
Data Memory 2048	1234h	0A089h
Data Memory 2049	2005h	2DCEh
Data Memory 2050	0E98Ch	3A9Fh

Syntax [*label*] BLZ *pma* [,{ind} [, *next ARP*]]

Operands
$0 \leq$ pma ≤ 65535
$0 \leq$ next ARP ≤ 7

Execution
If (ACC) < 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR(ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	0	0	1	1	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the contents of the accumulator are less than zero. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs when nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BLZ    PRG481   ;481 is loaded into the program counter if
                ;the accumulator is less than zero.
```

Syntax [*label*] BNC *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65535
$0 \le$ next ARP ≤ 7

Execution
If carry bit C = 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR(ARP) and ARP as specified.

Affected by C.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	1	0	1	1	1	1	1	1	See Section 4.1						
Program Memory Address															

Description
The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address if the carry bit C is low. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs when nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Note that the carry bit C is affected by all add, subtract, and accumulate instructions as well as the ABS, LST1, NEG, RC, SC, rotate, and shift instructions. The carry bit is not affected by execution of the BC, BNC, or nonarithmetic instructions.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BNC   PRG325   ;If the carry bit C = 0, 325 is loaded into
               ;program counter. Otherwise, the PC is the
               ;incremented by 2.
```

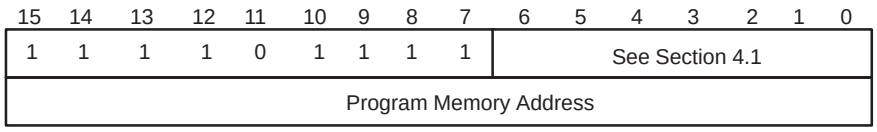
Syntax [*label*] BNV *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65535
$0 \le$ next ARP ≤ 7

Execution
If overflow OV status bit = 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC and 0 $\rightarrow$ OV.
Modify AR(ARP) and ARP as specified.

Affects OV; affected by OV.

Encoding



Description
The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the OV (overflow flag) is clear. Otherwise, the OV is cleared, and control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

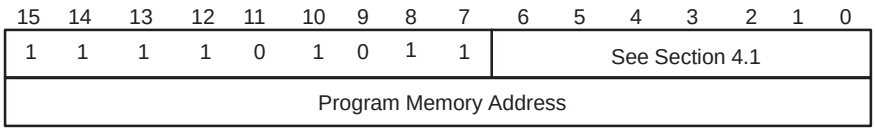
```
BNV   PRG315   ;315 is loaded into the program counter if the
               ;overflow flag is clear.  OV is cleared.
```

Syntax [*label*] BNZ *pma* [,{ind} [, *next ARP*]]

Operands
$0 \leq$ pma ≤ 65535
$0 \leq$ next ARP ≤ 7

Execution
If (ACC) $\neq 0$:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR(ARP) and ARP as specified.

Encoding



Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the contents of the accumulator are not equal to zero. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BNZ   PRG320   ;320 is loaded into the program counter if the
               ;accumulator does not equal zero.
```

Syntax

[*label*] BV *pma* [,{ind} [, *next ARP*]]

Operands

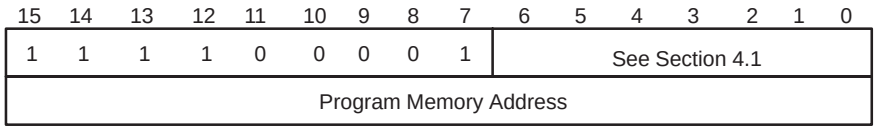
$0 \leq$ pma ≤ 65535
$0 \leq$ next ARP ≤ 7

Execution

If overflow (OV) status bit = 1:
  Then pma $\rightarrow$ PC and $0 \rightarrow$ OV;
Else (PC) + $2 \rightarrow$ PC.
  Modify AR(ARP) and ARP as specified.

Affects OV; affected by OV.

Encoding



Description

The current auxiliary register and ARP are modified as specified, and the overflow flag is cleared. Control passes to the designated program memory address (pma) if the OV (overflow flag) is set. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words

2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BV    PRG610   ;If an overflow has occurred since the overflow
               ;flag was last cleared, then 610 is loaded in
               ;the program counter and OV is cleared.
```

Syntax [*label*] BZ *pma* [,{ind} [, *next ARP*]]

Operands
$0 \leq$ pma ≤ 65535
$0 \leq$ next ARP ≤ 7

Execution
If (ACC) = 0:
Then pma $\rightarrow$ PC;
Else (PC) + 2 $\rightarrow$ PC.
Modify AR(ARP) and ARP as specified.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	0	1	1	0	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified. Control then passes to the designated program memory address (pma) if the contents of the accumulator are equal to zero. Otherwise, control passes to the next instruction. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
True Conditions: Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
False Condition: Destination anywhere:					
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
BZ    PRG102   ;102 is loaded into the program counter if
               ;the accumulator is equal to zero.
```

Syntax [*label*] CALA

Operands None

Execution (PC) + 1 → TOS
(ACC(15–0)) → PC

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	0	0	1	0	0

Description The current program counter is incremented and pushed onto the top of the stack. Then, the contents of the lower half of the accumulator are loaded into the PC. The carry bit on the TMS320C25 is unaffected by this instruction.

The CALA instruction is used to perform computed subroutine calls.

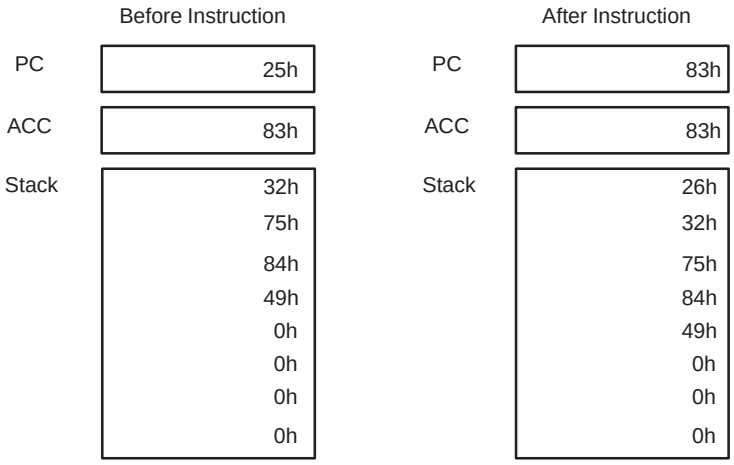
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Destination on-chip RAM:					
2	2	2+p	2+p	2	2
Destination on-chip ROM:					
3	3	3+p	3+p	3	3
Destination external memory:					
3+p	3+p	3+2p	3+2p	3+p	3+p
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
CALA
```



Syntax [*label*] CALL *pma* [,{ind} [, *next ARP*]]

Operands
$0 \le$ pma ≤ 65535
$0 \le$ next ARP ≤ 7

Execution
(PC) + 2 $\rightarrow$ TOS
pma $\rightarrow$ PC

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	1	1	0	1	See Section 4.1						
Program Memory Address															

Description The current auxiliary register and ARP are modified as specified, and the PC (program counter) is incremented by two and pushed onto the top of the stack. The specified program memory address (pma) is then loaded into the PC. Note that no AR or ARP modification occurs if nothing is specified in those fields. The pma can be either a symbolic or a numeric address.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Destination on-chip RAM:					
2	2	2+2p	2+2p	2	2
Destination on-chip ROM:					
3	3	3+2p	3+2p	3	3
Destination external memory:					
3+p	3+p	3+3p	3+3p	3+p	3+p
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
CALL    PRG109
```

pma

	Before Instruction	After Instruction
PC	33h	6Dh
Stack	71h	35h
	48h	71h
	16h	48h
	80h	16h
	0h	80h
	0h	0h
	0h	0h
	0h	0h

Syntax [*label*] CMPL

Operands None

Execution

$(\underline{PC}) + 1 \rightarrow PC$
$(\overline{ACC}) \rightarrow ACC$

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	0	0	1	1	1

Description The contents of the accumulator are replaced with its logical inversion (1s complement).

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
CMPL
```

Syntax [*label*] CMPR *constant*

Operands $0 \leq CM \leq 3$

Execution (PC) + 1 → PC
Compare AR(ARP) to AR0, placing result in TC bit of status register ST1.

Affects TC.
Not affected by SXM; does not affect SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	1	0	1	0	0	CM	

Description The CMPR instruction performs the following comparisons dependent on the value of CM:

If CM = 00, test if AR(ARP) = AR0
If CM = 01, test if AR(ARP) < AR0
If CM = 10, test if AR(ARP) > AR0
If CM = 11, test if AR(ARP) ≠ AR0

If the result of a test is true, a one is loaded into the TC status bit. Otherwise, TC is loaded with a zero. The auxiliary registers are treated as unsigned integers in the comparison.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
CMPR  2        ;(ARP = 4)
```

	Before Instruction	After Instruction
AR0	0FFFFh	0FFFFh
AR4	7FFFh	7FFFh
TC	1h	0h

Syntax [*label*] CNFD

Operands None

Execution (PC) + 1 → PC
0 → RAM configuration control (CNF) status bit

Affects CNF.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	1	0	0

Description On-chip RAM block 0 is configured as data memory. The block is mapped to locations 512 through 767 in data memory. This instruction is the complement of the CNFP instruction and sets the CNF bit in status register ST1 to a zero. CNF is also loaded by the CNFP and LST1 instructions.

On the TMS320C25, the next two instruction fetches immediately following a CNFD or CNFP instruction use the old value of CNF.

On the TMS320C26 this instruction is not valid and is undefined.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
CNFD        ;A zero is loaded into the CNF status bit,
            ;thus configuring block B0 as data memory
            ;(see memory maps in Section 3.4).
```

Syntax [*label*] CNFP

Operands None

Execution (PC) + 1 → PC
1 → RAM configuration control (CNF) status bit

Affects CNF.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	1	0	1

Description On-chip RAM block 0 is configured as program memory. The block is mapped to locations 65280 through 65535 in program memory space. This instruction is the complement of the CNFD instruction and sets the CNF bit in status register ST1 to a one. CNF is also loaded by the CNFD and LST1 instruction.

Configuring this block as program memory allows the use of the program counter as an address generator to access data from on-chip RAM. Used in conjunction with the repeat instructions, this allows two data memory locations to be addressed simultaneously, one from the auxiliary registers and one from the program counter. Instructions that take advantage of this feature are the MAC, MACD, BLKD, and BLKP instructions.

On the TMS320C25, the next two instruction fetches immediately following a CNFD or CNFP instruction use the old value of CNF.

On the TMS320C26, this instruction is not valid and is undefined.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
CNFP        ;The CNF bit is set to a logic 1, thus
            ;configuring block B0 as program memory
            ;(see memory maps in Section 3.4).
```

Syntax [*label*] CONF *constant*

Operands o ≤ constant ≤ 3

Execution (PC) + 1 → PC
Constant → program/data memory configuration mode status bits

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	1	1	CNF1	CNF0

Description The two low-order CNF bits of the instruction word are copied into the CNF0 and CNF1 field of status register ST1. The CNF0 and CNF1 status bits configure the on-chip RAM blocks into program or data memory. The bit combinations and their meanings are shown below in the CONF mode decoding table.

Words 1

Cycles

	Cycle Timings for a Single Instruction					
	PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
TMS320C26	1	1	1+p	1+p	1	1
	Cycle Timings for a Repeat Execution					
TMS320C26	n	n	n+p	n+p	n	n

CONF Mode Decoding Table

CNF1	CNF0	B0	B1	B2	B3
0	0	data	data	data	data
0	1	program	data	data	data
1	0	program	program	data	data
1	1	program	program	data	program

Example

```
CONF 2          ;Status register bit CNF1 is set to 1 and
                ;Status register bit CNF0 is set to 0, thus
                ;configuring the blocks B0 and B1 as
                ;program memory, B2 and B3 as data memory.
```

Syntax [*label*] DINT

Operands None

Execution (PC) + 1 → PC
1 → interrupt mode (INTM) status bit

Affects INTM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	1

Description The interrupt mode (INTM) status bit is set to logic 1. Maskable interrupts are disabled immediately after the DINT instruction executes. Note that the LST instruction does not affect INTM.

The unmaskable interrupt, $\overline{RS}$, is not disabled by this instruction, and the interrupt mask register (IMR) is unaffected. Interrupts are also disabled by a reset.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
DINT          ;Maskable interrupts are disabled, and INTM is
              ;set to one.
```

Syntax

Direct: [*label*] DMOV *dma*
Indirect: [*label*] DMOV {ind} [,<next ARP>]

Operands

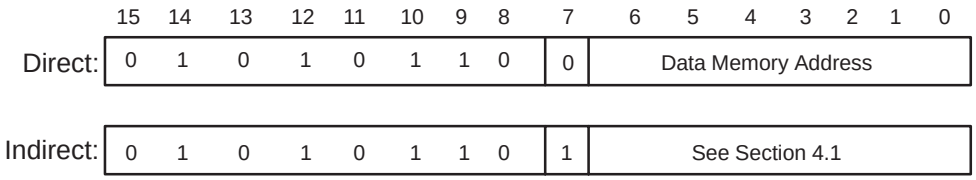
$0 \le dma \le 127$
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma) → dma + 1

Affected by CNF.

Encoding



Description

The contents of the specified data memory address are copied into the contents of the next higher address. DMOV works only within the on-chip data RAM blocks B0, B1, and B2. It works within block B0 if it is configured as data memory and the data move function is continuous across the boundaries of blocks B0 and B1; that is, it works for locations 512 to 1023. The data move function cannot be used on external data memory. If used on external data memory or memory-mapped registers, DMOV will read the specified memory location but will perform no other operations.

When data is copied from the addressed location to the next higher location, the contents of the addressed location remain unaltered.

The data move function is useful in implementing the z^{-1} delay encountered in digital signal processing. The DMOV function is included in the LTD and MACD instructions (see the LTD and MACD instructions or more information).

Words

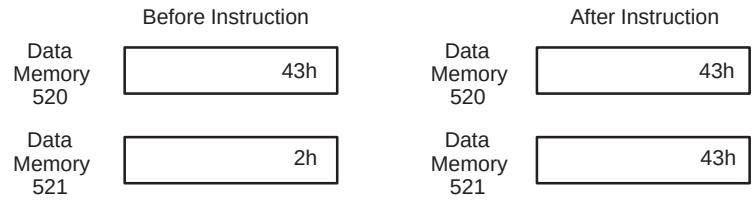
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
DMOV  DAT8     ;(DP=4)
or
DMOV  *        ;If current auxiliary register contains 520.
```



Syntax [*label*] EINT

Operands None

Execution (PC) + 1 → PC
0 → interrupt-mode (INTM) status bit

Affects INTM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0

Description The interrupt-mode flag (INTM) in the status register is cleared to logic 0. Maskable interrupts are enabled after the instruction following EINT executes. This allows an interrupt service routine to re-enable interrupts and execute a RET instruction before any other pending interrupts are processed. Note that the LST instruction does not affect INTM. (See the DINT instruction for further information.)

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
EINT        ;Unmasked interrupts are enabled, and INTM is
            ;set to zero.
```

Syntax [*label*] FORT *constant*

Operands Constant = 0 or 1

Execution (PC) + 1 → PC
Constant → format (FO) status bit

Affects FO.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	1	1	1	FO

Description The format (FO) status bit is loaded by the instruction with the LSB specified in the instruction. The FO bit is used to control the formatting of the transmit and receive shift registers of the serial port. If FO = 0, the registers are configured to receive/transmit 16-bit words. If FO = 1, the registers are configured to receive/transmit 8-bit bytes. FO is set to zero on a reset.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
FORT  1       ;The FO status bit is loaded with 1, making the
              ;bit length of the serial port 8 bits.
```

Syntax [*label*] IDLE

Operands None

Execution **TMS320C25**:

(PC) + 1 → PC

0 → interrupt mode (INTM) status bit

Affects INTM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	1	1	1

Description The IDLE instruction forces the program being executed to wait until an interrupt or reset occurs. The PC is incremented only once, and the device remains in an idle state until interrupted. On the TMS320C25, INTM is automatically set to zero. Execution of the IDLE instruction causes the TMS320C25 to enter the powerdown mode (see subsection 3.6.7). The on-chip timer continues to operate normally after execution of an IDLE instruction.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
(Interrupt) destination on-chip ROM 3 (min waits for INT) (Interrupt) destination external memory: 3+2p (min waits for INT)					
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
IDLE          ;The processor idles until a reset or
              ;unmasked interrupt occurs.
```

Syntax

Direct: [*label*] IN *dma*,*PA*
Indirect: [*label*] IN {ind}, *PA* [, *next ARP*]

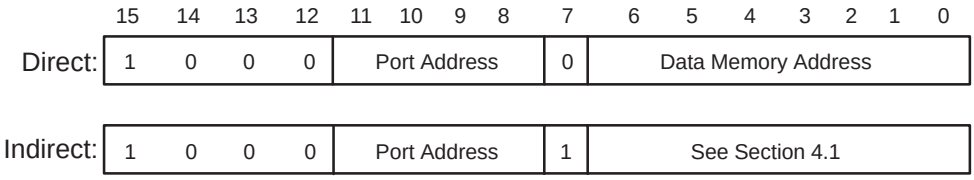
Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7
$0 \leq$ port address PA ≤ 15

Execution

(PC) + 1 → PC
Port address → address bus A3–A0
0 → address bus A15–A4
Data bus D15–D0 → dma

Encoding



Description

The IN instruction reads a 16-bit value from one of the external I/O ports into the specified data memory location. The $\overline{IS}$ line goes low to indicate an I/O access, and the $\overline{STRB}$, R/$\overline{W}$, and READY timings are the same as for an external data memory read.

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2+i	2+d+i	2+p+i	3+d+p+i	2+i	2+d+i
Cycle Timings for a Repeat Execution					
1+n+ni	2n+nd+ni	1+n+p+ni	1+2n+nd+p+ni	1+n+ni	2n+nd+ni

Example

```
IN STAT,PA5    ;Read in word from peripheral on port address
               ;5. Store in data memory location STAT.
or
LRLK  1,520    ;Load AR1 with decimal 520.
LARP  1        ;Load ARP with decimal 520.
IN    *-,PA1,0 ;Read in word from peripheral on port address
               ;1. Store in data memory location 520.
               ;Decrement AR1 to 519.
               ;Load the ARP with 0.
```

Syntax

Direct: [*label*] LAC *dma* [, *shift*]
Indirect : [*label*] LAC {ind} [, *shift* [, *next ARP*]]

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ shift ≤ 15 (defaults to 0)

Execution

(PC) + 1 $\rightarrow$ PC
(dma) x $2^{\text{shift}} \rightarrow$ ACC

If SXM = 1:
  Then (dma) is sign-extended.
If SXM = 0:
  Then (dma) is not sign-extended.

Affected by SXM.

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	0	0	1	0	Shift				0	Data Memory Address						
Indirect:	0	0	1	0	Shift				1	See Section 4.1						

Description

The contents of the specified data memory address are left-shifted and loaded into the accumulator. During shifting, low-order bits are zero-filled. High-order bits are sign-extended if SXM = 1 and zeroed if SXM = 0.

Words

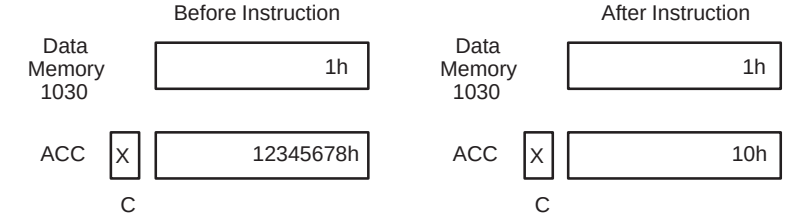
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LAC DAT6,4      ;(DP = 8)
or
LAC *,4         ;If current auxiliary register contains 1030.
```



Syntax [*label*] LACK *constant*

Operands $0 \leq$ constant ≤ 255

Execution (PC) + 1 → PC
8-bit positive constant → ACC

Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	0	1	0	8-Bit Constant							

Description The 8-bit constant is loaded into the accumulator right-justified. The upper 24 bits of the accumulator are zeroed (that is, sign extension is suppressed).

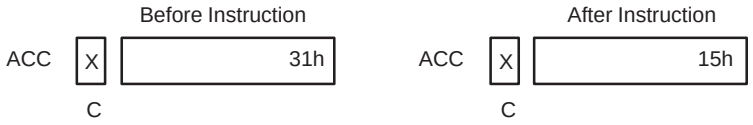
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
LACK  15h
```



Syntax

Direct: [*label*] LACT *dma*
Indirect: [*label*] LACT {ind} [, *next ARP*]

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

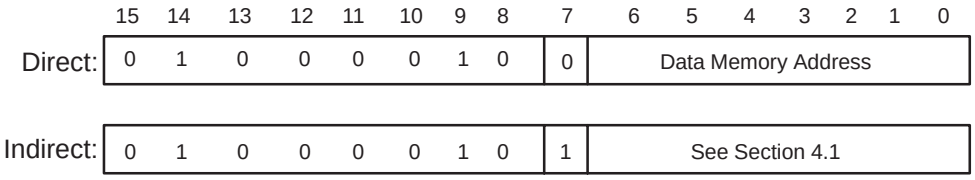
Execution

(PC) + 1 $\rightarrow$ PC
(dma) x 2^T register(3–0) $\rightarrow$ ACC

If SXM = 1:
Then (dma) is sign-extended.
If SXM = 0:
Then (dma) is not sign-extended.

Affected by SXM.

Encoding



Description

The LACT instruction loads the accumulator with a data memory value that has been left-shifted. The left-shift is specified by the four LSBs of the T register, resulting in shift options from 0 to 15 bits. Using the T register's contents as a shift code provides a variable shift mechanism.

LACT may be used to denormalize a floating-point number if the actual exponent is placed in the four LSBs of the T register and the mantissa is referenced by the data memory address. Note that this method of denormalization can be used only when the magnitude of the exponent is four bits or less.

Words

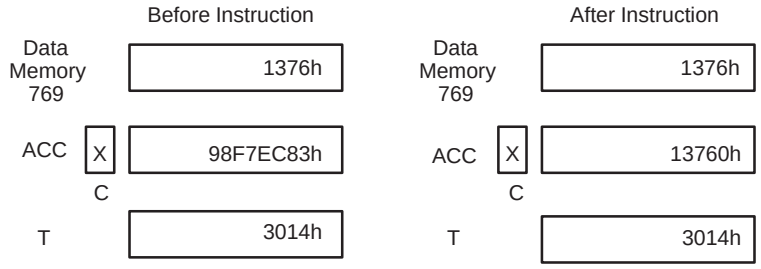
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LACT  DAT1     ;(DP = 6)
or
LACT  *        ;If current auxiliary register contains 769.
```



Syntax [*label*] LALK *constant* [, *shift*]

Operands
16-bit constant
0 ≤ shift ≤ 15 (defaults to 0)

Execution
(PC) + 2 → PC
Constant x 2^{shift} → ACC

If SXM = 1:
Then –32768 ≤ constant ≤ 32767.
If SXM = 0:
Then 0 ≤ constant ≤ 65535.

Affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	shift				0	0	0	0	0	0	0	1
16-Bit Constant															

Description
The left-shifted 16-bit immediate value is loaded into the accumulator. The shifted 16-bit constant is sign-extended if SXM = 1; otherwise, the high-order bits of the accumulator (past the shift) are set to zero. Note that the MSB of the accumulator can be set only if SXM = 1 and a negative number is loaded. The shift count is optional and defaults to zero.

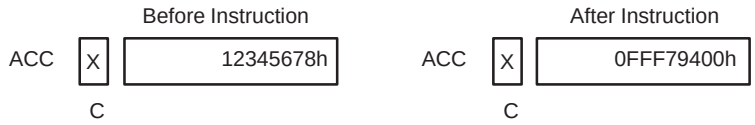
Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example 1

```
LALK  0F794h,8   ;(SXM=1):
```



Example 2

```
LALK  0F794h,8   ;(SXM=0):
```

Syntax

Direct: [*label*] LAR *AR dma*
Indirect:[*label*] LAR *AR*, {ind} [, *next ARP*]

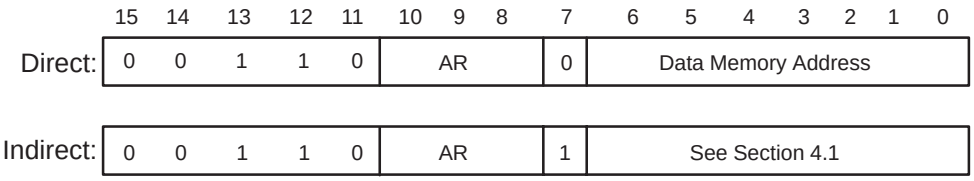
Operands

$0 \le$ dma ≤ 127
$0 \le$ auxiliary register AR ≤ 7
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(dma) $\rightarrow$ auxiliary register AR

Encoding



Description

The contents of the specified data memory address are loaded into the designated auxiliary register (AR).

The LAR and SAR (store auxiliary register) instructions can be used to load and store the auxiliary registers during subroutine calls and interrupts. If an auxiliary register is not being used for indirect addressing, LAR and SAR enable the register to be used as an additional storage register, especially for swapping values between data memory locations without affecting the contents of the accumulator.

Words

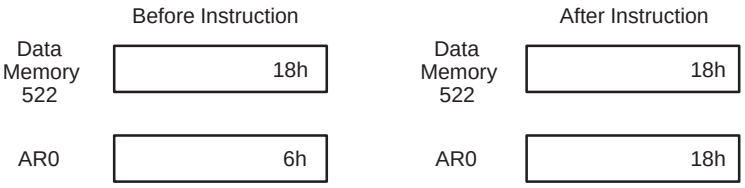
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	2n+nd	n+p	2n+nd+p	n	2n+nd

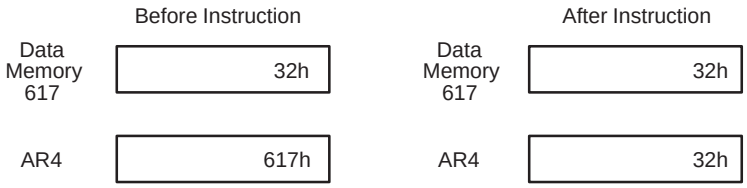
Example 1

```
LAR   AR0,DAT10 ;(DP = 4)
```



Example 2

```
LARP  AR4
LAR   AR4,*–
```



Note:

LAR, in the indirect addressing mode, ignores any AR modifications if the AR specified by the instruction is the same as that pointed to by the ARP. Therefore, in Example 2, AR4 is not decremented after the LAR instruction.

Syntax

[*label*] LARK *AR*, constant

Operands

$0 \leq$ constant ≤ 255
$0 \leq$ auxiliary register AR ≤ 7

Execution

(PC) + 1 → PC
8-bit constant → auxiliary register AR

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	0	AR			8-Bit Constant							

Description

The 8-bit positive constant is loaded into the designated auxiliary register (AR) right-justified and zero-filled (that is, sign-extension suppressed).

LARK is useful for loading an initial loop counter value into an auxiliary register for use with the BANZ instruction.

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
LARK  AR0,15
```

Before Instruction		After Instruction	
AR0	0h	AR0	15h

Syntax [*label*] LARP *constant*

Operands 0 ≤ constant ≤ 7

Execution

(PC) + 1 → PC
(ARP) → ARB
Constant → ARP

Affects ARP and ARB.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	1	0	1	0	1	0	1	1	0	0	0	1	ARP		

Description

The auxiliary register pointer is loaded with the contents of the three LSBs of the instruction (a 3-bit constant identifying the desired auxiliary register). The old ARP is copied to the ARB field of status register ST1. ARP can also be modified by the LST, LST1, and MAR instructions, as well as any instruction that is used in the indirect addressing mode.

The LARP instruction is a subset of MAR; that is, the opcode is the same as MAR in the indirect addressing mode. The following instruction has the same effect as LARP:

```
MAR *,constant
```

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
LARP  1       ;Any succeeding instructions will use auxiliary
              ;register AR1 for indirect addressing.
```

Syntax

Direct: [*label*] LDP *dma*
Indirect: [*label*] LDP {ind} [, *next ARP*]

Operands

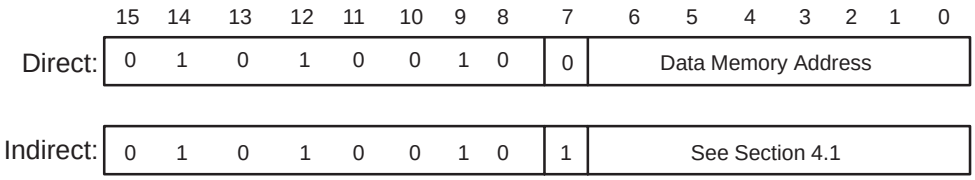
$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 → PC
Nine LSBs of (dma) → data page pointer register (DP) status bits

Affects DP.

Encoding



Description

The nine LSBs of the contents of the addressed data memory location are loaded into the DP (data memory page pointer) register. The DP and 7-bit data memory address are concatenated to form 16-bit data memory addresses. The DP may also be loaded by the LST and LDPK instructions.

Words

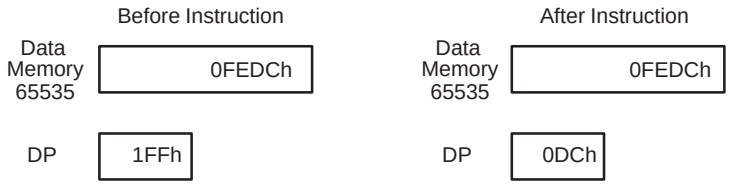
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	2n+nd	n+p	2n+nd+p	n	2n+nd

Example

```
LDP   DAT127   ;(DP = 511)
or
LDP   *        ;If current auxiliary register contains 65535.
```



Syntax [*label*] LDPK *constant*

Operands $0 \leq$ constant $\leq$ 511

Execution (PC) + 1 → PC
Constant → data memory page pointer (DP) status bits

Affects DP.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	0	0	DP								

Description The DP (data memory page pointer) register is loaded with a 9-bit constant. The DP and 7-bit data memory address are concatenated to form 16-bit direct data memory addresses. DP ≥ 8 specifies external data memory. DP = 4 through 7 specifies on-chip RAM blocks B0 or B1. Block B2 is located in the upper 32 words of page 0. DP may also be loaded by the LST and LDP instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
LDPK  64      ;The data page pointer is set to 64.
```

Syntax

Direct: [*label*] LPH *dma*
Indirect: [*label*] LPH {ind} [, *next ARP*]

Operands

0 ≤ dma ≤127
0 ≤ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma) → P register (31 – 16)

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	0	1	0	1	0	0	1	1	0	Data Memory Address						
Indirect:	0	1	0	1	0	0	1	1	1	See Section 4.1						

Description

The P register high-order bits are loaded with the contents of data memory. The low-order P register bits are unaffected.

The LPH instruction is particularly useful for restoring the high-order bits of the P register after subroutine calls or interrupts.

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LPH   DAT0     ;(DP = 4)
or
LPH   *        ;If current auxiliary register contains 512.
```

	Before Instruction		After Instruction
Data Memory 512	0F79Ch	Data Memory 512	0F79Ch
P	30079844h	P	F79C9844h

Syntax [*label*] LRLK *AR*, *constant*

Operands $0 \leq$ auxiliary register ≤ 7
$0 \leq$ constant ≤ 65535

Execution (PC) + 2 → PC
Constant → AR

Not affected by SXM; does not affect SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	0	AR			0	0	0	0	0	0	0	0
16-Bit Constant															

Description The 16-bit immediate value is loaded into the auxiliary register specified by the AR field. The specified constant must be an unsigned integer, and its value is not affected by SXM.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
LRLK  AR3,3080h
```

	Before Instruction		After Instruction
AR3	7F80h	AR3	3080h

Syntax

Direct: [*label*] LST *dma*
Indirect: [*label*] LST {ind} [, *next ARP*]

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(dma) $\rightarrow$ status register ST0

Affects ARP, OV, OVM, and DP.
Does not affect INTM or ARB.

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	0	1	0	1	0	0	0	0	0	Data Memory Address						
Indirect:	0	1	0	1	0	0	0	0	1	See Section 4.1						

Description

Status register ST0 is loaded with the addressed data memory value. Note that the INTM (interrupt mode) bit is unaffected by LST. ARB is also unaffected even though a new ARP is loaded. If a next ARP value is specified via the indirect addressing mode, the specified value is ignored. Instead, ARP is loaded with the value contained within the addressed data memory word.

The LST instruction is used to load status register ST0 after interrupts and subroutine calls. The ST0 contains the status bits: OV (overflow flag) bit, OVM (overflow mode) bit, INTM (interrupt mode) bit, ARP (auxiliary register pointer), and DP (data memory page pointer). These bits were stored (by the SST instruction) in the data memory word as follows:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARP			OV	OVM	1	INTM	DP								

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	2n+nd	n+p	2n+nd+p	n	2n+nd

Example 1

```
LARP  0
LST   *,1      ;The data memory word addressed by the contents
               ;of auxiliary register AR0 is loaded into
               ;status register ST0, except for the INTM bit.
               ;Note that even though a next ARP value is
               ;specified, that value is ignored, and even
               ;though a new ARP is loaded, the old ARP is not
               ;loaded into ARB.
```

Example 2

```
LST   60h      ;(DP = 0)
```

	Before Instruction	After Instruction
Data Memory 96	2404h	2404h
ST0	6E00h	2604h
ST1	0580h	0580h

Example 3

```
LARP  AR4      ;(AR4 = 3FFh)
LST   *–
```

	Before Instruction	After Instruction
AR4	3FFh	3FEh
Data Memory 1023	0CE06h	0CE06h
ST0	0FC04h	0CC06h
ST1	0E780h	0E780h

Example 4

```
LARP  AR4      ;(AR4= 3FFh)
LST   *–,1
```

	Before Instruction	After Instruction
AR4	3FFh	3FEh
Data Memory 1023	0EE04h	0EE04h
ST0	0EE00h	0EE04h
ST1	0F780h	0F780h

Syntax

```
Direct:     [ label ]    LST1    dma
Indirect:   [ label ]    LST1    {ind} [, next ARP ]
```

Operands

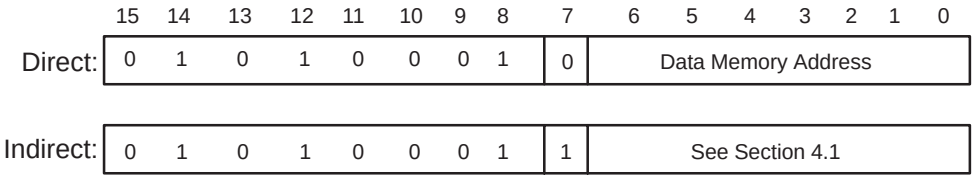
$0 \le dma \le 127$
$0 \le next\ ARP \le 7$

Execution

(PC) + 1 → PC
(dma) → status register ST1
(ARB) → ARP

Affects ARP, ARB, CNF, TC, SXM, XF, FO, TXM, and PM.
Affects C, HM, and FSM (TMS320C25)

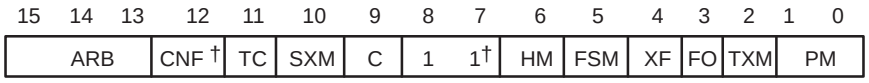
Encoding



Description

Status register ST1 is loaded with the data memory value. The bits of the data memory value, which are loaded into ARB, are also loaded into ARP to facilitate context switching. Note that if a next ARP value is specified via the indirect addressing mode, the specified value is ignored.

LST1 is used to load status bits after interrupts and subroutine calls. ST1 contains these status bits: ARB (auxiliary register pointer buffer), CNF (RAM configuration control), TC (test/control), SXM (sign-extension mode), XF (external flag), FO (serial port format), TXM (transmit mode), and the PM (product register shift mode). ST1 on the TMS320C25 also contains status bits: C (carry), HM (hold mode), and FSM (frame synchronization mode). The bits loaded into status register ST1 from the data memory word are as follows:



† On the TMS320C26, bits 12 and 7 hold CONF0 and CNF1, respectively (see the CONF instruction for decoding).

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	2n+nd	n+p	2n+nd+p	n	2n+nd

Example 1

```
LARP  3
LST1  *–      ;The data memory word addressed by the contents
              ;of auxiliary register AR3 replaces the status
              ;bits of status register ST1, and AR3 is
              ;decremented.
```

Example 2

```
LST1  61h     ;(DP = 0)
```

	Before Instruction	After Instruction
Data Memory 97	0580h	0580h
ST0	0AC00h	0C00h
ST1	0581h	0580h

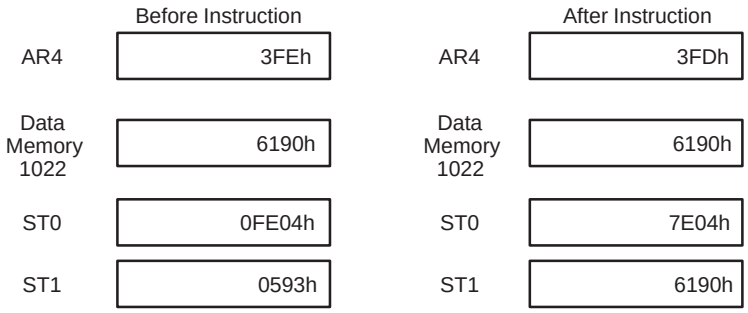
Example 3

```
LARP  AR4     ;(AR4 = 3FEh)
LST1  *–
```

	Before Instruction	After Instruction
AR4	3FEh	3FDh
Data Memory 1022	4F90h	4F90h
ST0	0FC04h	5C04h
ST1	0E780h	4F90h

Example 4

```
LARP  AR4      ;(AR4 = 3FEh)
LST1  *-,1
```



Syntax

Direct: [*label*] LT *dma*
Indirect: [*label*] LT {ind} [, *next ARP*]

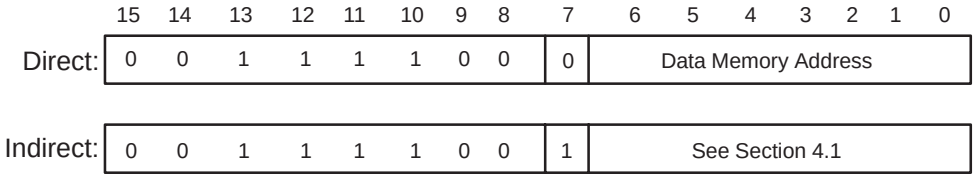
Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(dma) $\rightarrow$ T register

Encoding



Description

The T register is loaded with the contents of the specified data memory address (dma). The LT instruction may be used to load the T register in preparation for multiplication. See the LTA, LTD, LTP, LTS, MPY, MPYK, MPYA, MPYS, and MPYU instructions.

Words

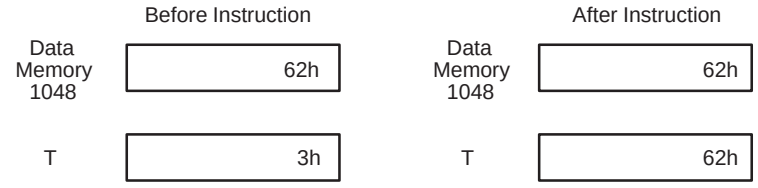
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LT    DAT24    ;(DP = 8)
or
LT    *        ;If current auxiliary register contains 1048.
```



Syntax

Direct:	[*label*]	LTA	*dma*
Indirect:	[*label*]	LTA	{ind} [, *next ARP*]

Operands

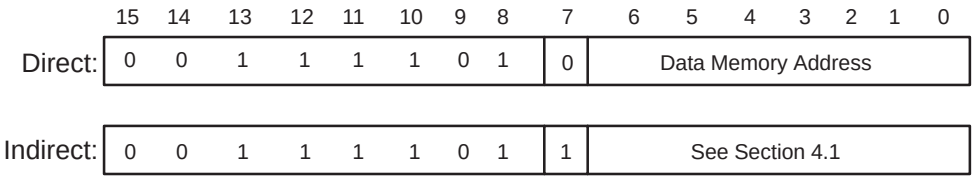
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma) → T register
(ACC) + (shifted P register) → ACC

Affects OV; affected by OVM and PM.
Affects C.

Encoding



Description

The T register is loaded with the contents of the specified data memory address (dma). The contents of the product register, shifted as defined by the PM status bits, are added to the accumulator, with the result left in the accumulator.

The function of the LTA instruction is included in the LTD instruction.

Words

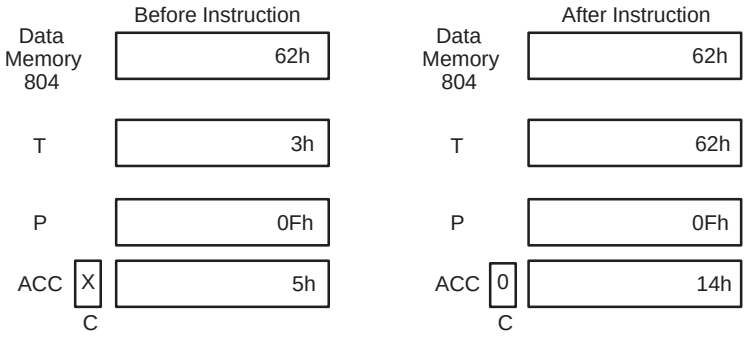
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LTA   DAT36    ;(DP = 6, PM = 0)
or
LTA   *        ;If current auxiliary register contains 804.
```



Syntax

Direct:	[*label*]	LTD	*dma*
Indirect:	[*label*]	LTD	{ind} [, *next ARP*]

Operands

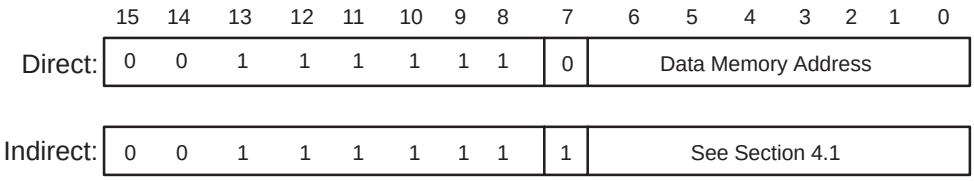
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma) → T register
(dma) → dma + 1
(ACC) + (shifted P register) → ACC

Affects OV; affected by OVM and PM.
Affects C.

Encoding



Description

The T register is loaded with the contents of the specified data memory address (dma). The contents of the P register, shifted as defined by the PM status bits, are added to the accumulator, and the result is placed in the accumulator. The contents of the specified data memory address are also copied to the next higher data memory address.

This instruction is valid for blocks B1 and B2 and is also valid for block B0 if block B0 is configured as data memory. The data move function is continuous across the boundary of blocks B0 and B1 but cannot be used with external data memory or memory-mapped registers. This function is described under the instruction DMOV. Note that if used with external data memory, the function of LTD is identical to that of LTA.

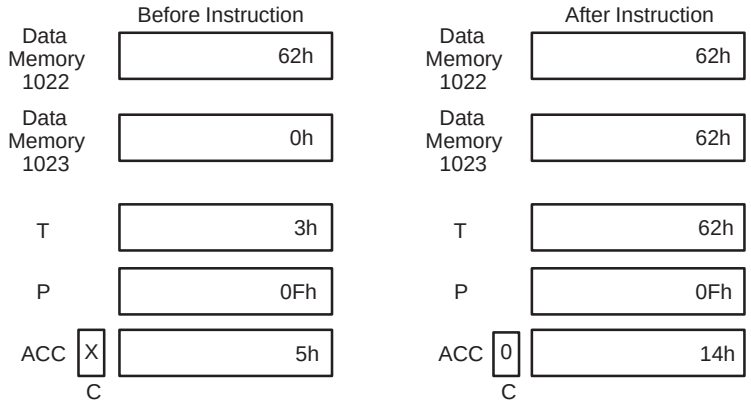
Words

1

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LTD   DAT126   ;(DP = 7, PM = 0)
or
LTD   *        ;If current auxiliary register contains 1022.
```



Syntax

Direct: [*label*] LTP *dma*
Indirect: [*label*] LTP {ind} [, *next ARP*]

Operands

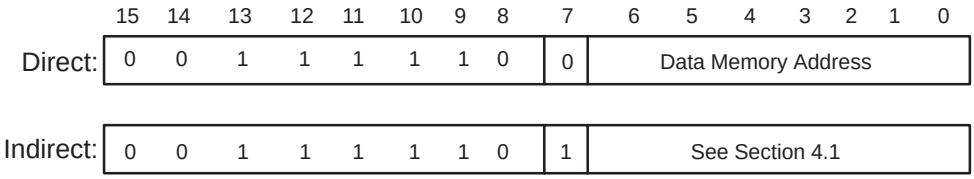
$0 \le dma \le 127$
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma) → T register
(shifted P register) → ACC

Affected by PM.

Encoding



Description

The T register is loaded with the contents of the addressed data memory location, and the product register is stored in the accumulator. The shift at the output of the product register is controlled by the PM status bits.

Words

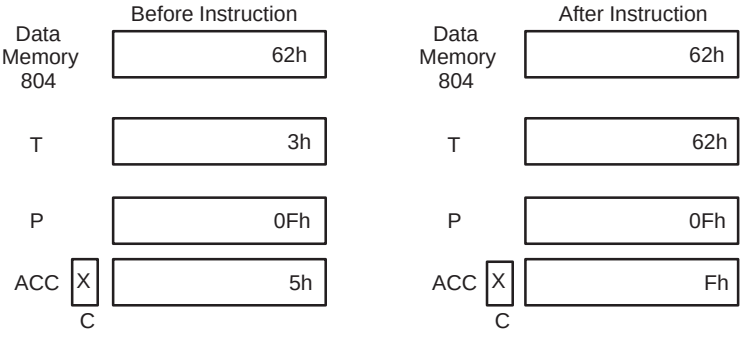
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LTP   DAT36    ;(DP = 6, PM = 0)
or
LTP   *        ;If current auxiliary register contains 804.
```



Syntax

Direct:	[*label*]	LTS	*dma*
Indirect:	[*label*]	LTS	[ind] [, *next ARP*]

Operands

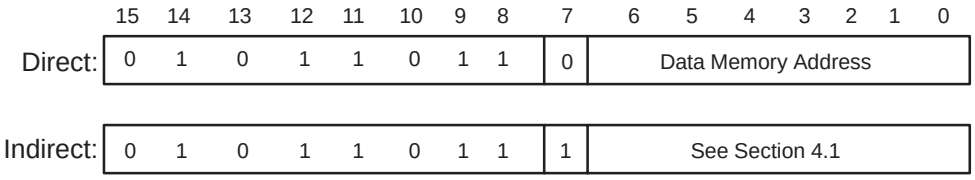
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma) → T register
(ACC) – (shifted P register) → ACC

Affects OV; affected by PM and OVM.
Affects C.

Encoding



Description

The T register is loaded with the contents of the addressed data memory location. The contents of the product register, shifted as defined by the contents of the PM status bits, are subtracted from the accumulator. The result is left in the accumulator.

Words

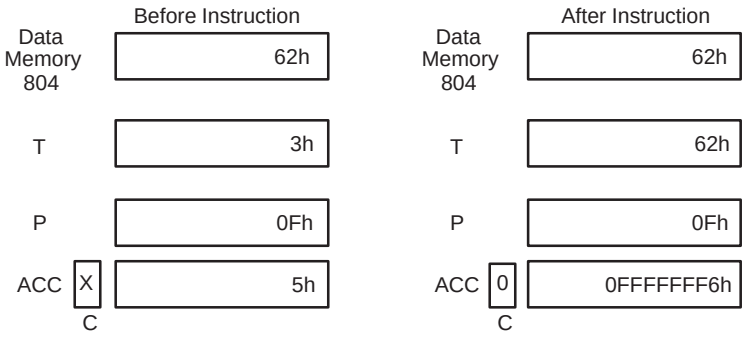
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
LTS   DAT36    ;(DP = 6, PM = 0)
or
LTS *          ;If current auxiliary register contains 804.
```



Syntax

Direct: [*label*] MAC *pma*, *dma*
Indirect: [*label*] MAC *pma*, {ind} [, *next ARP*]

Operands

$0 \le$ pma ≤ 65535
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

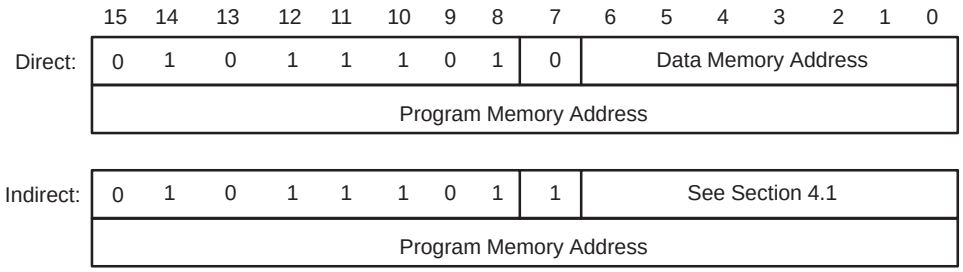
TMS320C25:

(PC) + 2 → PC
(PFC) → MCS
(pma) → PFC

If (repeat counter) ≠ 0:
  Then (ACC) + (shifted P register) → ACC,
  (dma) → T register,
  (dma) × (pma, addressed by PFC) → P register,
  Modify AR(ARP) and ARP as specified,
  (PFC) + 1 → PFC,
  (repeat counter) – 1 → repeat counter.
Else (ACC) + (shifted P register) → ACC
  (dma) → T register
  (dma) × (pma, addressed by PFC) → P register
  Modify AR(ARP) and ARP as specified.
  (MCS) → PFC

Affects C and OV; affected by OVM and PM.

Encoding


15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Direct:
0 1 0 1 1 1 0 1 0
Data Memory Address
Program Memory Address
Indirect:
0 1 0 1 1 1 0 1 1
See Section 4.1
Program Memory Address

Description

The MAC instruction multiplies a data memory value (specified by dma) by a program memory value (specified by pma). It also adds the previous product, shifted as defined by the PM status bits, to the accumulator.

The data and program memory locations on the TMS320C25 may be any non-reserved, on-chip or off-chip memory locations. If the program memory is block B0 of on-chip RAM, then the CNF bit must be set to one. Note that the upper eight bits of the program memory address should be set to 0FFh in order to address B0 program RAM, and the upper six bits of dma should be set to 0 to address a location below 1024. When used in the direct addressing mode, the dma cannot be modified during repetition of the instruction.

When the MAC instruction is repeated, the program memory address contained in the PC/PFC is incremented by one during its operation. This enables accessing a series of operands in memory. MAC is useful for long sum-of-products operations, since MAC becomes a single-cycle instruction once the RPT pipeline is started.

Words 2

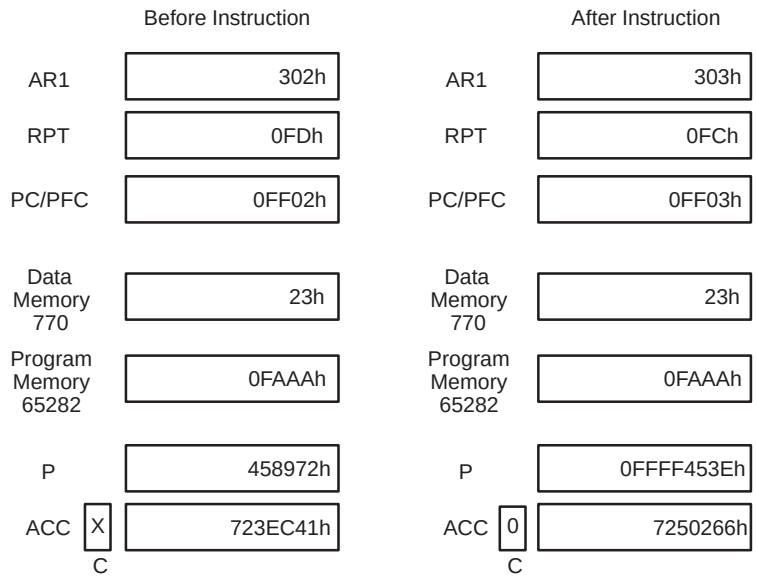
Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Table in on-chip RAM:					
3	4+d	4+2p	5+d+2p	4	5+d
Table in on-chip ROM:					
4	5+d	4+2p	5+d+2p	4	5+d
Table in external memory:					
4+p	5+d+p	4+3p	5+d+3p	4+p	5+d+p
Cycle Timings for a Repeat Execution					
Table in on-chip RAM:					
2+n	2+2n+nd	3+n+2p	3+2n+nd+2p	3+n	3+2n+nd
Table in on-chip ROM:					
3+n	3+2n+nd	3+n+2p	3+2n+nd+2p	3+n	3+2n+nd
Table in external memory:					
3+n+np	3+2n+nd +np	3+n+np +2p	3+2n+nd+p +2p	3+n+np	3+2n+nd +np

Example

```
SPM   3          ;Select a shift-right-by-6 mode on PR output.
                 ;on PR output.
CNFP             ;Configure block B0 as program memory
                 ;(0FFXXh).
LARP  1          ;Use AR1 to address block B1.
LRLK  1,768      ;Point to lowest location in RAM block B1
RPTK  255        ;Compute 256 sum-of-product operations.
MAC   0FF00h,*+ ;Multiply/accumulate and increment AR1.
```

The following example shows register and memory contents before and after the third step repeat loop:



Syntax

Direct: [*label*] MACD *pma*, *dma*
Indirect: [*label*] MACD *pma*, {ind} [, *next ARP*]

Operands

$0 \le$ pma ≤ 65535
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

TMS320C25:

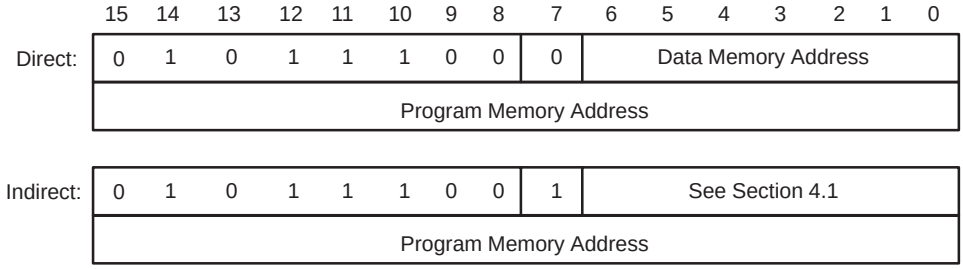
(PC) + 2 → PC
(PFC) → MCS
(pma) → PFC

If (repeat counter) ≠ 0:
Then (ACC) + (shifted P register) → ACC,
(dma) → T register,
(dma) × (pma, addressed by PFC) → P register,
(dma) → dma + 1,
Modify AR(ARP) and ARP as specified,
(PFC) + 1 → PFC,
(repeat counter) – 1 → repeat counter.

Else (ACC) + (shifted P register) → ACC
(dma) → T register,
(dma) × (pma, addressed by PFC) → P register
(dma) → dma + 1,
Modify AR(ARP) and ARP as specified.
(MCS) → PFC

Affects C and OV; affected by OVM and PM.

Encoding


15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Direct:
0 1 0 1 1 1 0 0 0
Data Memory Address
Program Memory Address
Indirect:
0 1 0 1 1 1 0 0 1
See Section 4.1
Program Memory Address

Description

The MACD instruction multiplies a data memory value (specified by dma) by a program memory value (specified by pma). It also adds the previous product, shifted as defined by the PM status bits, to the accumulator.

The data and program memory locations on the TMS320C25 may be any non-reserved, on-chip or off-chip memory locations. If the program memory is block B0 of on-chip RAM, then the CNF bit must be set to one. Note that the upper eight bits of the program memory address should be set to 0FFh in order

to address B0 program RAM, and the upper six bits of dma should be set to 0 to address a location below 1024. When used in the direct addressing mode, the dma cannot be modified during repetition of the instruction. If MACD addresses one of the memory-mapped registers or external memory as a data memory location, the effect of the instruction will be that of a MAC instruction (see the DMOV instruction description).

MACD functions in the same manner as MAC, with the addition of data move for block B0, B1, or B2. Otherwise, the effects are the same as for MAC. This feature makes MACD useful for applications such as convolution and transversal filtering.

When the MACD instruction is repeated, the program memory address contained in the PC/PFC is incremented by one during its operation. This enables accessing a series of operands in memory. When used with RPT or RPTK, MACD becomes a single-cycle instruction, once the RPT pipeline is started.

Note:

The data move function for MACD can occur only within the data blocks B0 – B2 of the on-chip RAM. B3 can also be used for the TMS320C26.

Words 2

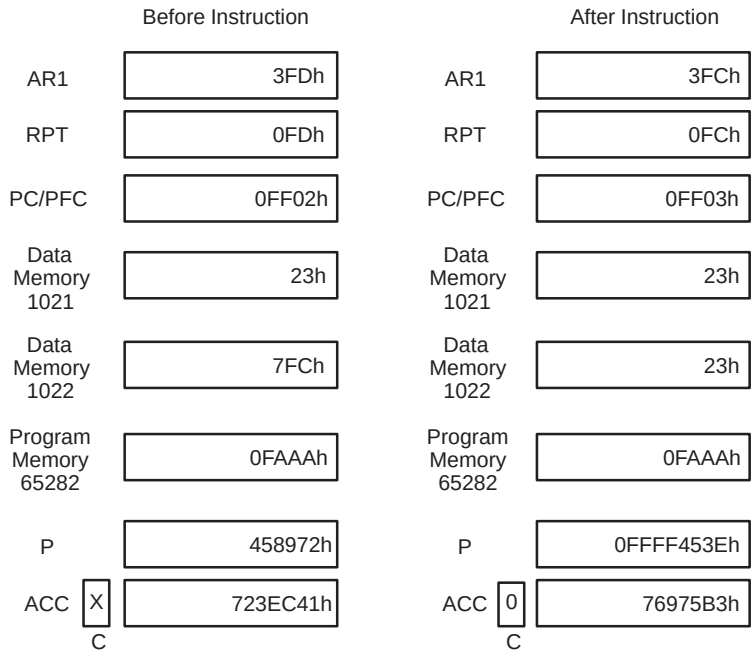
Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Table in on-chip RAM:					
3	4+d	4+2p	5+d+2p	4	5+d
Table in on-chip ROM:					
4	5+d	4+2p	5+d+2p	4	5+d
Table in external memory:					
4+p	5+d+p	4+3p	5+d+3p	4+p	5+d+p
Cycle Timings for a Repeat Execution					
Table in on-chip RAM:					
2+n	2+2n+nd	3+n+2p	3+2n+nd+2p	3+n	3+2n+nd
Table in on-chip ROM:					
3+n	3+2n+nd	3+n+2p	3+2n+nd+2p	3+n	3+2n+nd
Table in external memory:					
3+n+np	3+2n+nd +np	3+n+np +2p	3+2n+nd+np +2p	3+n+np	3+2n+nd +np

Example

```
SPM   0          ;Select no shift mode on PR output.
SOVM             ;Set overflow mode.
CNFP             ;Configure block B0 as program memory
                 ;(0FFXXh).
LARP  3          ;Use AR3 to address block B1.
LRLK  3,1023     ;Point to highest location in RAM block B1.
RPTK  255        ;Compute 1 sample of a length-256
                 ;convolution.
MACD  0FF00h,*–  ;Multiply/accumulate, shift data word in
                 ;block B1 and decrement AR3.
```

The following example shows register and memory contents before and after the third step repeat loop:



Syntax

Direct: [*label*] MAR *dma*
Indirect: [*label*] MAR {ind} [, *next ARP*]

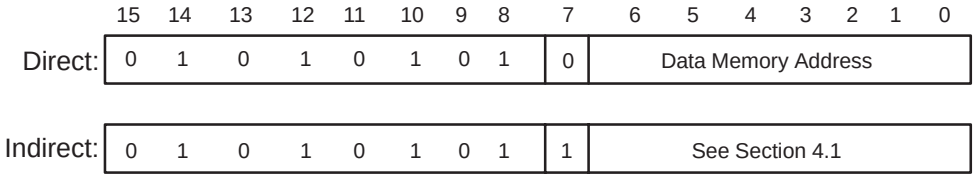
Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
Modifies ARP, AR(ARP) as specified by the indirect addressing field (acts as a NOP in direct addressing).

Encoding



Description

The MAR instruction acts as a no-operation instruction in the direct addressing mode. In the indirect addressing mode, the auxiliary registers and the ARP are modified; however, no use is made of the memory being referenced. MAR is used only to modify the auxiliary registers or the ARP. If a next ARP is specified, the old ARP is copied to the ARB field of status register ST1. Note that any operation that MAR performs can also be performed with any instruction that supports indirect addressing. ARP may also be loaded by an LST instruction.

In the direct addressing mode, MAR is a NOP. Also, the instruction LARP is a subset of MAR (that is, MAR *,4 performs the same function as LARP 4).

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example 1

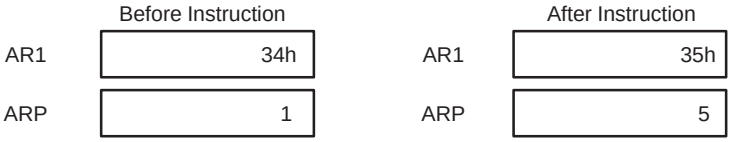
```
MAR   *,1      ;Load the ARP with 1.
```

Example 2

```
MAR   *–       ;Decrement current auxiliary register (in this
               ;case, AR1).
```

Example 3

```
MAR   *+,5     ;Increment current auxiliary register (AR1) and
               ;load ARP with 5.
```



Syntax

Direct: [*label*] MPY *dma*
Indirect: [*label*] MPY {ind} [, *next ARP*]

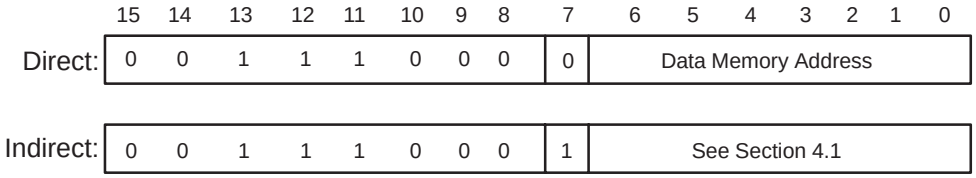
Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(T register) $\times$ (dma) $\rightarrow$ P register

Encoding



Description

The contents of the T register are multiplied by the contents of the addressed data memory location. The result is placed in the P register.

Words

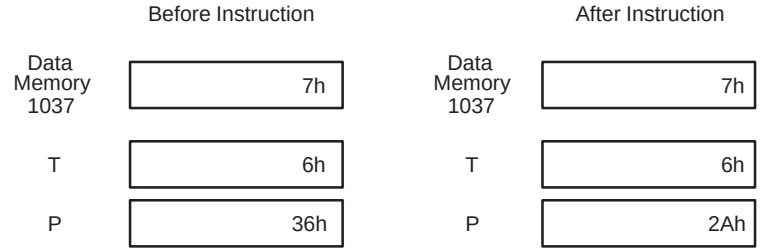
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
MPY   DAT13    ;(DP = 8)
```
or
```
MPY   *        ;If current auxiliary register contains 1037.
```



Syntax

Direct: [*label*] MPYA *dma*
Indirect: [*label*] MPYA {ind} [, *next ARP*]

Operands

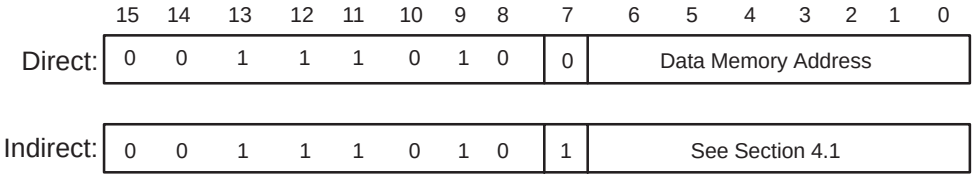
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC) + (shifted P register) → ACC
(T register) × (dma) → P register

Affects C and OV; affected by OVM and PM.

Encoding



Description

The contents of the T register are multiplied by the contents of the addressed data memory location. The result is placed in the P register. The previous product, shifted as defined by the PM status bits, is also added to the accumulator.

Words

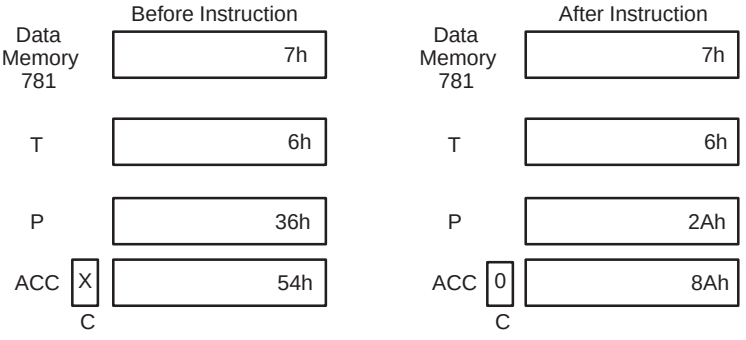
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
MPYA  DAT13    ;(DP = 6, PM = 0)
or
MPYA  *        ;If current auxiliary register contains 781.
```



Syntax [*label*] MPYK *constant*

Operands $-4096 \leq \text{constant} \leq 4095$
$-2^{12} \leq \text{constant} \leq 2^{12} - 1$

Execution (PC) + 1 → PC
(T register) × constant → P register

Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	0	1	13-Bit Constant												

Description The contents of the T register are multiplied by the signed, 13-bit constant. The result is loaded into the P register. The immediate field is right-justified and sign-extended before multiplication, regardless of SXM.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
MPYK  -9
```

	Before Instruction		After Instruction
T	7h	T	7h
P	2Ah	P	0FFFFFFC1h

Syntax

Direct: [*label*] MPYS *dma*
Indirect: [*label*] MPYS {ind} [, *next ARP*]

Operands

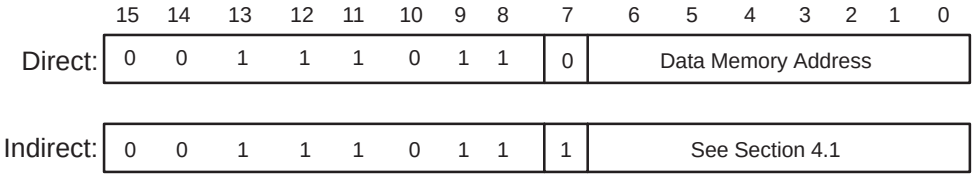
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC) – (shifted P register) → ACC
(T register) × (dma) → P register

Affects C and OV; affected by OVM and PM.

Encoding



Description

The contents of the T register are multiplied by the contents of the addressed data memory location. The result is placed in the P register. The previous product, shifted as defined by the PM status bits, is also subtracted from the accumulator.

Words

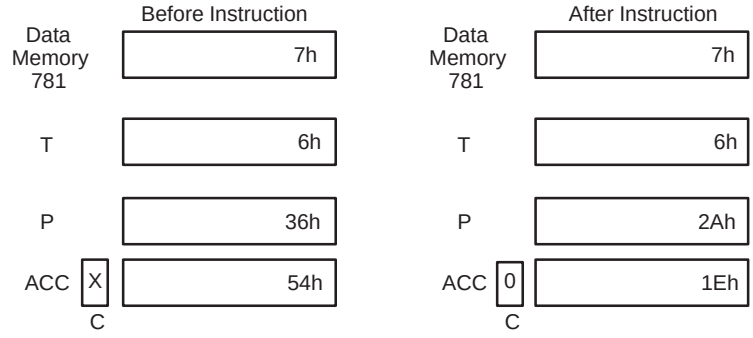
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
MPYS DAT13     ;(DP = 6, PM = 0)
or
MPYS *         ;If current auxiliary register contains 781.
```



Syntax

Direct: [*label*] MPYU *dma*
Indirect : [*label*] MPYU {ind} [, *next ARP*]

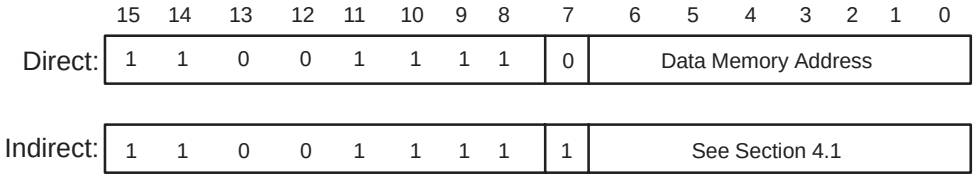
Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
Unsigned (T register) $\times$ unsigned (dma) $\rightarrow$ P register

Encoding



Description

The unsigned contents of the T register are multiplied by the unsigned contents of the addressed data memory location. The result is placed in the P register. Note that the multiplier acts as a 17 $\times$17-bit signed multiplier for this instruction, with the MSB of both operands forced to zero.

The shifter at the output of the P register will always invoke sign-extension on the P register when PM = 3 (right-shift by 6 mode). Therefore, this shift mode should not be used if unsigned products are desired.

The MPYU instruction is particularly useful for computing multiple-precision products, such as when multiplying two 32-bit numbers to yield a 64-bit product.

Words

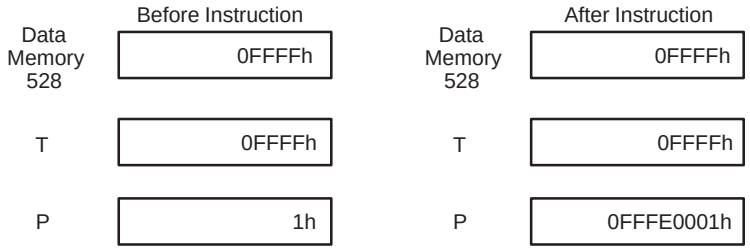
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
MPYU  DAT16    ;(DP = 4)
or
MPYU  *        ;If current auxiliary register contains 528.
```



Syntax [*label*] NEG

Operands None

Execution (PC) + 1 → PC
(ACC) × –1 → ACC

Affects OV; affected by OVM.
Affects C.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	0	0	0	1	1

Description The contents of the accumulator are replaced with its arithmetic complement (2s complement). The OV bit is set when taking the NEG of 80000000h. If OVM = 1, the accumulator contents are replaced with 7FFFFFFFh. If OVM = 0, the result is 80000000h. The carry bit C on the TMS320C2x is reset to zero by this instruction for all nonzero values of the accumulator and is set to one if the accumulator equals zero.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
NEG
```

NOP *No Operation*

Syntax [*label*] NOP

Operands None

Execution (PC) + 1 → PC

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0

Description No operation is performed. The NOP instruction affects only the PC. NOP functions in the same manner as the MAR instruction in the direct addressing mode; NOP has the same opcode as MAR in the direct addressing mode with dma = 0.

The NOP instruction is useful as a pad or temporary instruction during program development.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
NOP
```

Syntax [*label*] NORM {ind} (TMS320C25)

Operands None

Execution **TMS320C25:**

(PC) + 1 → PC
If (ACC) = 0:
  Then 1 → TC;
Else, if (ACC(31)) XOR (ACC(30)) = 0:
  Then 0 → TC,
  (ACC) × 2 → ACC,
  Modify AR(ARP) as specified;
Else 1 → TC.

Affects TC.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	1	Modify AR			0	0	1	0

Description The NORM instruction is provided for normalizing a signed number that is contained in the accumulator. Normalizing a fixed-point number separates it into a mantissa and an exponent. To do this, the magnitude of a sign-extended number must be found. ACC bit 31 is exclusive-ORed with ACC bit 30 to determine if bit 30 is part of the magnitude or part of the sign extension. If they are the same, they are both sign bits, and the accumulator is left-shifted to eliminate the extra sign bit.

The AR(ARP) is modified as specified to generate the magnitude of the exponent. It is assumed that AR(ARP) is initialized before the normalization begins. The default modification of the AR(ARP) is an increment.

Multiple executions of the NORM instruction may be required to completely normalize a 32-bit number in the accumulator. Although using NORM with RPT or RPTK does not cause execution of NORM to fall out of the repeat loop automatically when the normalization is complete, no operation is performed for the remainder of the repeat loop. Note that NORM functions on both positive and negative 2s-complement numbers.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example 1

```
31-Bit Normalization:

        LARP   1        ;Use AR1 for exponent storage.
        LARK   1,0      ;Clear out exponent counter.
LOOP    NORM *+         ;One bit is normalized.
        BBZ    LOOP     ;If TC = 0, magnitude not found yet.
```

Example 2

```
15-Bit Normalization:

 ARP  1                 ;Use AR1 to store the exponent.
 LARK 1,15              ;Initialize exponent counter.
 RPTK 14                ;15-bit normalization is specified
                        ;(yielding  a  4-bit  exponent  and
                        ;16-bit mantissa).
 NORM *–                ;NORM  automatically  stops  shifting
                        ;when the first significant magnitude
                        ;bit  is  found,  performing  NOPs  for
                        ;the remainder of the repeat loop.
```

The first method is used to normalize a 32-bit number and yields a 5-bit exponent magnitude. The second method is used to normalize a 16-bit number and yields a 4-bit exponent magnitude. If the number requires only a small amount of normalization, the first method may be preferable to the second. This results because Example 1 runs only until normalization is complete. Example 2 always executes all 15 cycles of the repeat loop. Specifically, Example 1 is more efficient if the number requires five or less shifts. If the number requires six or more shifts, Example 2 is more efficient.

Syntax

Direct: [*label*] OR *dma*
Indirect: [*label*] OR {ind} [, *next ARP*]

Operands

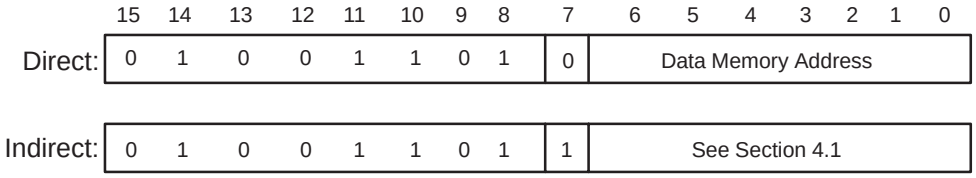
$0 \le dma \le 127$
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC(15–0)) OR dma → ACC(15–0)
(ACC(31–16)) → ACC(31–16)

Not affected by SXM.

Encoding



Description

The low-order bits of the accumulator are ORed with the contents of the addressed data memory location. The high-order bits of the accumulator are ORed with all zeros. Therefore, the upper half of the accumulator is unaffected by this instruction.

Words

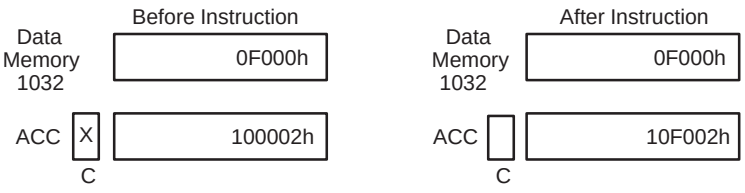
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
OR   DAT8        ;(DP = 8)
or
OR*              ;Where current auxiliary register contains
                 ;1032.
```



Syntax [*label*] ORK *constant* [,*shift*]

Operands
16-bit constant
0 ≤ shift ≤ 15 (defaults to 0)

Execution
(PC) + 2 → PC
(ACC(30–0)) OR [constant x 2^{shift}] → ACC(30–0)
(ACC(31)) → ACC(31)

Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	Shift				0	0	0	0	0	1	0	1
16-Bit Constant															

Description
The left-shifted 16-bit immediate constant is ORed with the accumulator. The result is left in the accumulator. Low-order bits below and high-order bits above the shifted value are treated as zeroes. The corresponding bits of the accumulator are unaffected. Note that the most significant bit of the accumulator is not affected, regardless of the shift code value.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
ORK   0FFFFh,8
```

Syntax

Direct: [*label*] OUT *dma*, *PA*
Indirect: [*label*] OUT {ind}, *PA* [, *next ARP*]

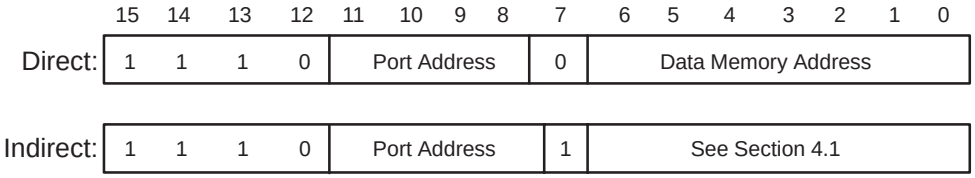
Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ port address PA ≤ 15

Execution

(PC) + 1 → PC
Port address PA → address bus A3 – A0
0 → address bus A15 – A4
(dma) → data bus D15 – D0

Encoding



Description

The OUT instruction writes a 16-bit value from a data memory location to the specified I/O port. The $\overline{IS}$ line goes low to indicate an I/O access, and the $\overline{STRB}$, R/$\overline{W}$, and READY timings are the same as for an external data memory write. OUT is a single-cycle instruction when in the PI/DI memory configuration (see Appendix D).

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1+i	2+d+i	2+p+i	3+d+p+i	1+i	2+d+i
Cycle Timings for a Repeat Execution					
n+ni	2n+nd+ni	1+n+p+ni	1+2n+nd+p +ni	n+ni	2n+nd+ni

Example

```
OUT   78h,7    ;(DP = 4) Output data word stored in data
               ;memory location 78h to peripheral on port
               ;address 7.
or
OUT   *,0Fh    ;Output data word referenced by current
               ;auxiliary register to peripheral on port
               ;address 0Fh.
```

Syntax [*label*] PAC

Operands None

Execution (PC) + 1 → PC
(shifted P register) → ACC

Affected by PM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	0	1	0	0

Description The contents of the P register are loaded into the accumulator, shifted as specified by the PM status bits.

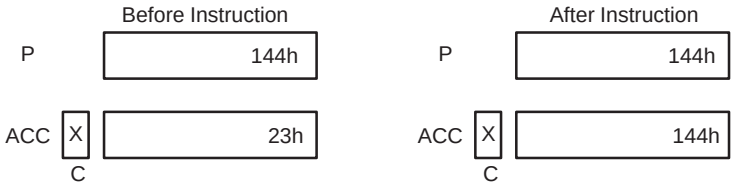
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
PAC             ;(PM = 0)
```



Syntax [*label*] POP

Operands None

Execution
(PC) + 1 → PC
(TOS) → ACC(15 – 0)
0 → ACC(31 –16)
Pop stack one level.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	1	0	1

Description The contents of the top of the stack (TOS) are copied to the low accumulator, and the stack is popped after the contents are copied. The upper half of the accumulator is set to all zeros.

The hardware stack is a last-in, first-out stack with eight (TMS320C2x) locations. Any time a pop occurs, every stack value is copied to the next higher stack location, and the top value is removed from the stack. After a pop, the bottom two stack words will have the same value. Because each stack value is copied, if more than seven pops (due to POP, POPD, or RET instructions) occur before any pushes occur, all levels of the stack contain the same value. No provision exists to check stack underflow.

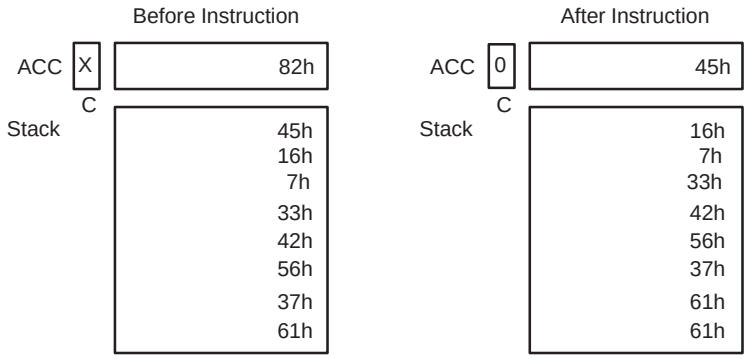
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
P0P
```



Syntax

Direct: [*label*] POPD *dma*
Indirect: [*label*] POPD {ind} [, *next ARP*]

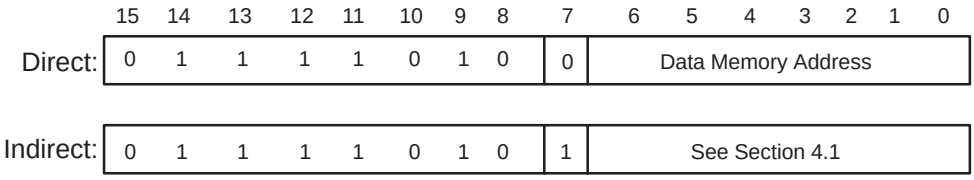
Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(TOS) → dma
POP stack one level.

Encoding



Description

The value from the top of the stack is transferred into the data memory location specified by the instruction. The values are also popped in the lower seven locations (TMS320C2x) of the stack. The hardware stack is described in the previous instruction POP. The lowest stack location remains unaffected. No provision exists to check stack underflow.

Words

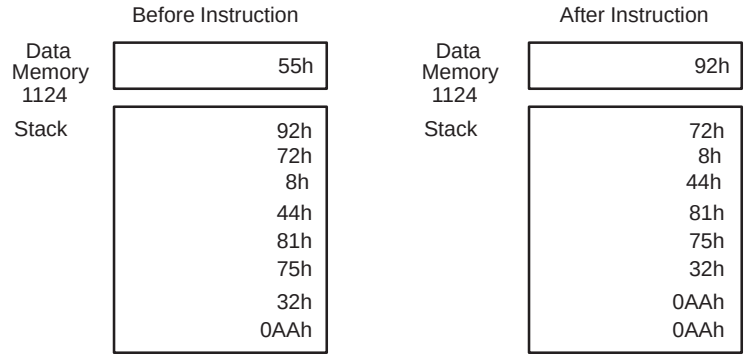
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

Example

```
POPD  DAT100   ;(DP = 8)
```
or
```
POPD  *        ;If current auxiliary register contains 1124.
```



Syntax

Direct: [*label*] PSHD *dma*
Indirect: [*label*] PSHD {ind} [, *next ARP*]

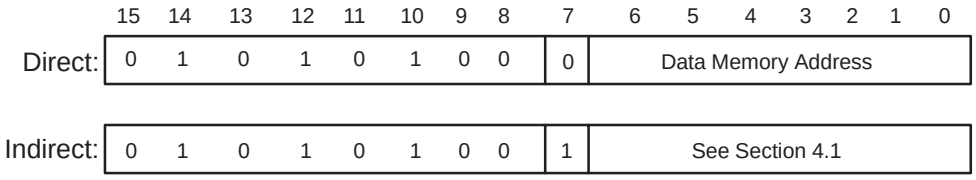
Operands

$0 \le dma \le 127$
$0 \le$ next ARP $\rightarrow 7$

Execution

(dma) $\rightarrow$ TOS
(PC) + 1 $\rightarrow$ PC
Push all stack locations down one level.

Encoding



Description

The value from the data memory location specified by the instruction is transferred to the top of the stack. The values are also pushed down in the lower seven locations (TMS320C2x) of the stack, as described in the instruction PUSH. The lowest stack location is lost.

Words

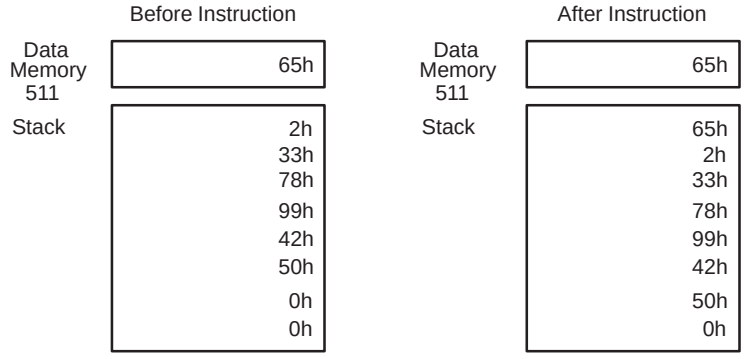
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
PSHD  DAT127   ;(DP = 3)
or
PSHD  *        ;If current auxiliary register contains 511.
```



Syntax [*label*] PUSH

Operands None

Execution (PC) + 1 → PC
Push all stack locations down one level.
(ACC(15–0)) → TOS

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	1	0	0

Description The contents of the lower half of the accumulator are copied onto the top of the hardware stack. The stack is pushed down before the accumulator value is copied.

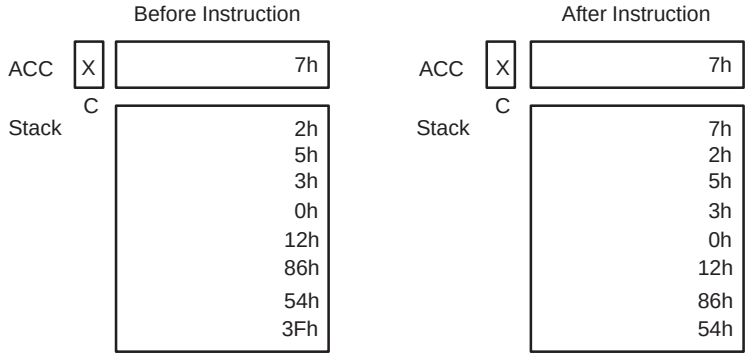
The hardware stack is a last-in, first-out stack with eight locations (TMS320C2x). If more than eight pushes (due to CALA, CALL, PSHD, PUSH, or TRAP instructions) occur before a pop, the first data values written will be lost with each succeeding push.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example PUSH:



Syntax [*label*] RC

Operands None

Execution (PC) + 1 → PC
0 → carry bit C in status register ST1

Affects C.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	0	0	0

Description The carry bit C in status register ST1 is reset to logic zero. The carry bit may also be loaded directly by the LST1 and SC instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RC              ;The carry bit C is reset to logic zero.
```

Syntax [*label*] RET

Operands None

Execution (TOS) → PC
Pop stack one level.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	0	0	1	1	0

Description The contents of the top stack register are copied into the program counter. The stack is then popped one level. RET is used with CALA and CALL for subroutines.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Destination on-chip RAM:					
2	2	2 + p	2 + p	2	2
Destination on-chip ROM:					
3	3	3 + p	3 + p	3	3
Destination external memory:					
3 + p	3 + p	3 + 2p	3 + 2p	3 + p	3 + p
Cycle Timings for a Repeat Execution					
not repeatable					

Example

RET

	Before Instruction	After Instruction
PC	96h	37h
Stack	37h 45h 75h 21h 3Fh 45h 6Eh 6Eh	45h 75h 21h 3Fh 45h 6Eh 6Eh 6Eh

Syntax [*label*] RFSM

Operands None

Execution (PC) + 1 → PC
0 → FSM status bit in status register ST1

Affects FSM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	1	1	0

Description The RFSM status bit resets the FSM status bit to logic zero. In this mode, external FSR pulses are not required to initiate the receive operation for each word received, but rather only one FSR pulse is required to initiate a continuous mode of operation. The same holds true for FSX when TXM = 0. After the first FSR/FSX pulse, these inputs are then in a don't care state. If TXM = 1, FSX is pulsed the first time DXR is loaded but remains low thereafter. See Section 3.9 for further details on the operation of the serial port. FSM may also be loaded by the LST1 and SFSM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RFSM        ;FSM is reset, putting the serial port in a
            ;mode of operation where frame
            ;synchronization pulses are not required.
            ;This allows a continuous bit stream to be
            ;transmitted/received without FSX/FSR pulses
            ;every 8/16 bits.
```

Syntax [*label*] RHM

Operands None

Execution (PC) + 1 → PC
0 → HM status bit in status register ST1

Affects HM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	1	0	0	0

Description The RHM instruction clears internal execution when acknowledging an active HOLD (HM = 1). When HM = 0, the processor may continue execution out of internal memory but puts its external interface in a high-impedance state.

HM can also be loaded by the LST1 and SHM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RHM             ;HM is reset, implementing the TMS320C25 hold
                ;mode for on-chip program execution.
```

Syntax [*label*] ROL

Operands None

Execution

(PC) + 1 → PC
(ACC(31)) → C
(ACC(30 – 0)) → ACC(31 –1)
(C, before ROL) → ACC(0)

Affects C.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	1	0	0

Description The ROL instruction rotates the accumulator left one bit. The MSB is shifted into the carry bit, and the value of the carry bit from before the execution of the instruction is shifted into the LSB.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
ROL
```

Syntax [*label*] ROR

Operands None

Execution

(PC) + 1 → PC
(ACC(0)) → C
(ACC(31–1)) → ACC(30–0)
(C, before ROR) → ACC(31)

Affects C.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	1	0	1

Description The ROR instruction rotates the accumulator right one bit. The LSB is shifted into the carry bit, and the value of the carry bit from before the execution of the instruction is shifted into the MSB.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
ROR
```

Syntax [*label*] ROVM

Operands None

Execution (PC) + 1 → PC
0 → OVM status bit in status register ST0

Affects OVM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	0	1	0

Description The OVM status bit is reset to logic zero, which disables the overflow mode. If an overflow occurs with OVM reset, the OV (overflow flag) is set, and the overflowed result is placed in the accumulator.

OVM may also be loaded by the LST and SOVM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
ROVM        ;The overflow mode bit OVM is reset, disabling
            ;the overflow mode on any subsequent arithmetic
            ;operations.
```

Syntax

Direct: [*label*] RPT *dma*
Indirect: [*label*] RPT {ind} [,*next ARP*]

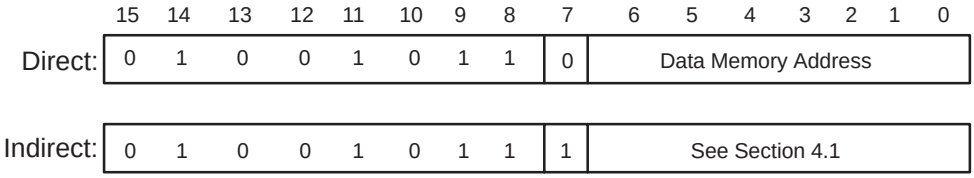
Operands

$0 \le dma \le 127$
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(dma(7–0)) → RPTC

Encoding



Description

The eight LSBs of the addressed data memory value are loaded into the repeat counter (RPTC). This causes the following instruction to be executed one time more than the number loaded into the RPTC (provided that it is a repeatable instruction). Interrupts are masked out until the next instruction has been executed the specified number of times. (Interrupts cannot be allowed during the RPT/next instruction sequence, because the RPTC cannot be saved during a context switch.) The RPTC counter is cleared on a $\overline{RS}$.

RPT and RPTK are especially useful for repeating instructions, such as BLKP, BLKD, IN, MAC, MACD, NORM, OUT, TBLR, TBLW, and others.

Words

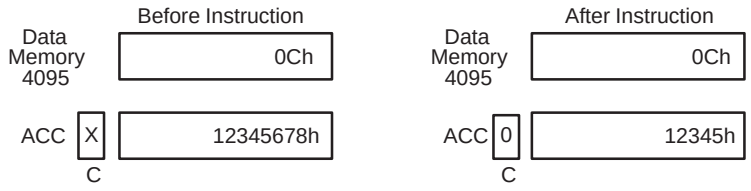
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2 + d
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
RPT   DAT127   ;(DP = 31)
SFR
or
RPT   *        ;If current auxiliary register contains 4095.
SFR
```



Syntax [*label*] RPTK *constant*

Operands $0 \le$ constant ≤ 255

Execution (PC) + 1 → PC
Constant → RPTC

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	0	1	1	8–Bit Constant							

Description The 8-bit immediate value is loaded into the RPTC (repeat counter). This causes the following instruction to be executed one time more than the number loaded into the RPTC (provided that it is a repeatable instruction). Interrupts are masked out until the next instruction has been executed the specified number of times. (Interrupts cannot be allowed during the RPT/next instruction sequence, because the RPTC cannot be saved during a context switch.) The RPTC is cleared on a $\overline{\text{RS}}$.

RPT and RPTK are especially useful for repeating instructions, such as BLKP, BLKD, IN, MAC, MACD, NORM, OUT, TBLR, TBLW, and others.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
LRLK  AR2,200h ;Load AR2 with the address of X.
LARP  2
ZAC            ;Clear the accumulator.
MPYK  0        ;Clear the P register.
RPTK  2        ;Repeat next instruction 3 times.
SQRA  *+       ;Compute X**2 + Y**2 + Z**2.
APAC
```

Syntax [*label*] RSXM

Operands None

Execution (PC) + 1 → PC
0 → SXM sign-extension mode status bit

Affects SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	1	1	0

Description The RSXM instruction resets the SXM status bit to logic zero, which suppresses sign-extension on shifted data memory values for the following arithmetic instructions: ADD, ADDT, ADLK, LAC, LACT, LALK, SBLK, SUB, and SUBT.

The RSXM instruction affects the definition of the SFR instruction. SXM may also be loaded by the LST1 and SSXM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RSXM          ;SXM is reset, disabling sign-extension on
              ;subsequent instructions.
```

Syntax [*label*] RTC

Operands None

Execution (PC) + 1 → PC
0 → TC test/control flag in status register ST1

Affects TC.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	0	1	0

Description The TC (test/control) flag in status register ST1 is reset to logic zero. TC can also be loaded by the LST1 and STC instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RTC             ;TC (test/control) flag is reset to logic zero.
```

Syntax [*label*] RTXM

Operands None

Execution (PC) + 1 → PC
0 → TXM transmit mode status bit

Affects TXM mode bit.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	0	0	0	0	0

Description The RTXM instruction resets the TXM status bit, which configures the serial port transmit section in a mode where it is controlled by an FSX (external framing pulse). The transmit operation is started when an external FSX pulse is applied. TXM may also be loaded by the LST1 and STXM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RTXM            ;TXM is reset, configuring FSX as an input.
```

Syntax [*label*] RXF

Operands None

Execution (PC) + 1 → PC
0 → XF external flag pin and status bit

Affects XF.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	1	1	0	0

Description The XF pin and XF status bit in status register ST1 are reset to logic zero. XF may also be loaded by the LST1 and SXF instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
RXF             ;XF pin and status bit are reset to logic zero.
```

Syntax

Direct: [*label*] SACH *dma* [, *shift*]
Indirect: [*label*] SACH {ind} [, *shift* [, *next ARP*]]

Operands

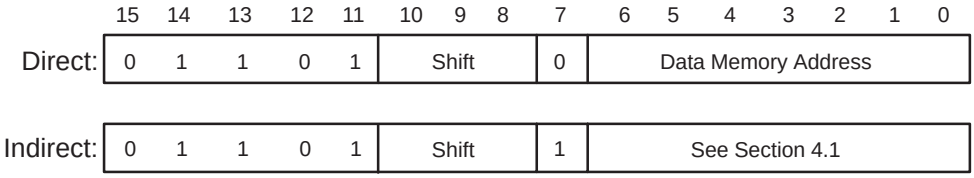
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ shift ≤ 7 (defaults to 0)

Execution

(PC) + 1 $\rightarrow$ PC
16 MSBs of (ACC) x $2^{shift} \rightarrow$ dma

Not affected by SXM.

Encoding



Description

The SACH instruction copies the entire accumulator into a shifter, where it shifts the entire 32-bit number anywhere from 0 to 7 bits on the TMS320C2x. It then copies the upper 16 bits of the shifted value into data memory. The accumulator itself remains unaffected.

Words

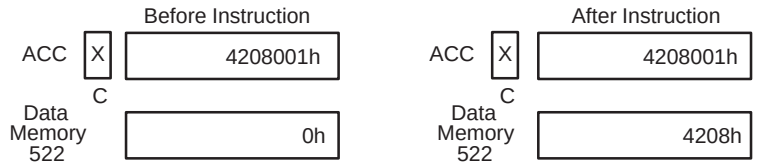
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

Example

```
SACH  DAT10,4   ;(DP = 4)
or
SACH  *,4       ;If current auxiliary register contains 522.
```



Syntax

Direct: [*label*] SACL *dma* [, *shift*]
Indirect: [*label*] SACL {ind} [, *shift* [, *next ARP*]]

Operands

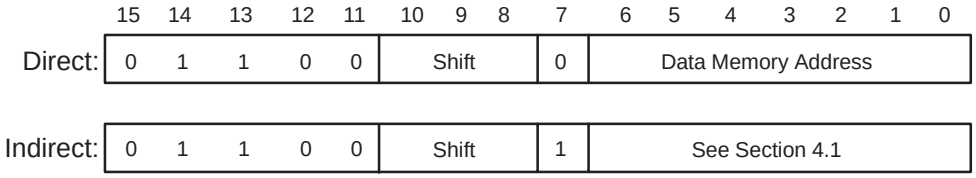
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ shift ≤ 7 (defaults to 0)

Execution

(PC) + 1 $\rightarrow$ PC
16 LSBs of (ACC) $\times 2^{\text{shift}} \rightarrow$ dma

Not affected by SXM.

Encoding



Description

The low-order bits of the accumulator are shifted left 0 to 7 bits on the TMS320C2x, as specified by the shift code, and stored in data memory. The low-order bits are filled with zeros, and the high-order bits are lost. The accumulator itself is unaffected.

Words

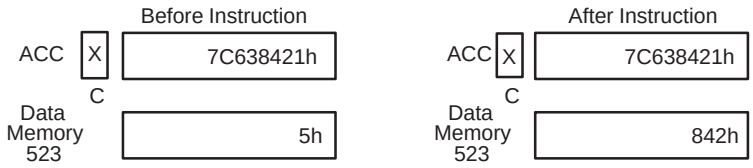
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

Example

```
SACL  DAT11,1  ;(DP = 4)
or
SACL  *,1      ;If current auxiliary register contains 523.
```



Syntax

Direct: [*label*] SAR *AR* , *dma*
Indirect: [*label*] SAR *AR* , {ind} [, *next ARP*]

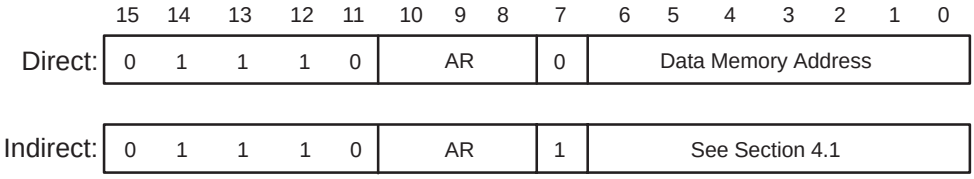
Operands

$0 \leq$ dma ≤ 127
$0 \leq$ auxiliary register AR ≤ 7
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(AR) $\rightarrow$ dma

Encoding



Description

The contents of the designated auxiliary register (AR) are stored in the addressed data memory location.

When you are modifying the contents of the current auxiliary register in the indirect addressing mode, SAR ARn (when n = ARP) stores the value of the auxiliary register contents before it is incremented, decremented, or indexed by AR0.

Words

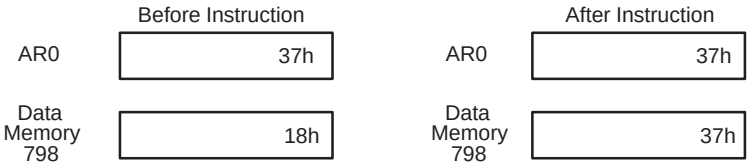
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

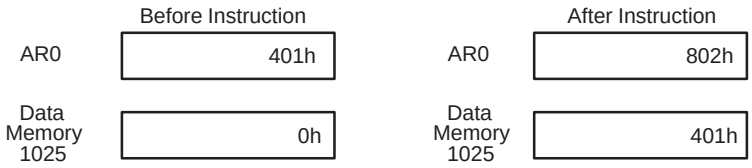
Example 1

```
SAR   AR0,DAT30 ;(DP = 6)
or
SAR   AR0,*     ;If current auxiliary register contains 798.
```



Example 2

```
LARP  AR0
SAR   AR0,*0+
```



Syntax [*label*] SBLK *constant* [, *shift*]

Operands 16-bit constant
$0 \le$ shift ≤ 15 (defaults to 0)

Execution (PC) + 2 $\rightarrow$ PC
(ACC) –[constant $\times 2^{\text{shift}}$] $\rightarrow$ ACC

If SXM = 1:
Then $-32768 \le$ constant ≤ 32767.
If SXM = 0:
Then $0 \le$ constant ≤ 65535.

Affects OV; affected by OVM and SXM.
Affects C.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	Shift				0	0	0	0	0	0	1	1
16-Bit Constant															

Description The immediate field of the instruction is subtracted from the accumulator. The result replaces the accumulator contents. SXM determines whether the constant is treated as a signed 2s-complement number or as an unsigned number. The shift count is optional and defaults to zero.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
SBLK  5,12
```

Syntax [*label*] SBRK *constant*

Operands 0 ≤ constant ≤ 255

Execution (PC) + 1 → PC
AR(ARP) – 8-bit positive constant → AR(ARP)

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	**1**	1	1	1	1	1	1	8-Bit Constant							

Description The 8-bit immediate value is subtracted, right-justified, from the currently selected auxiliary register with the result replacing the auxiliary register contents. The subtraction takes place in the ARAU, with the immediate value treated as an 8-bit positive integer.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
SBRK  0FFh      ;(ARP = 7)
```

	Before Instruction		After Instruction
AR7	0h	AR7	0FF01h

Syntax [*label*] SC

Operands None

Execution (PC) + 1 → PC
1 → carry bit C in status register ST1

Affects C.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	0	0	1

Description The carry bit C in status register ST1 is set to logic one. The carry bit may also be loaded directly by the LST1 and RC instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SC              ;Carry bit C is set to logic one.
```

Syntax [*label*] SFL

Operands None

Execution

(PC) + 1 → PC
(ACC(31)) → C
(ACC(30–0)) → ACC(31–1)
0 → ACC(0)

Affects C.
Not affected by SXM bit.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0

Description The SFL instruction shifts the entire accumulator left one bit. The least significant bit is filled with a zero. On the TMS320C2x, the most significant bit is shifted into the carry bit (C). Note that SFL, unlike SFR, is unaffected by SXM.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example SFL

Syntax [*label*] SFR

Operands None

Execution

(PC) + 1 → PC
If SXM = 0:
  Then (ACC(0)) → C
    (ACC(31–1)) → ACC (30–0) and 0 → ACC(31)
If SXM = 1:
  Then (ACC(0)) → C
    (ACC(31–1)) → ACC(30–0) and (ACC(31)) → ACC(31)

Affects C.

Affected by SXM bit.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	0	0	1

Description

The SFR instruction shifts the accumulator right one bit.

If SXM = 1, the instruction produces an arithmetic right shift. The sign bit (MSB) is unchanged and is also copied into bit 30. Bit 0 is shifted into the carry bit (C).

If SXM = 0, the instruction produces a logical right shift. All of the accumulator bits are shifted by one bit to the right. The least significant bit is shifted into the carry bit, and the most significant bit is filled with a zero.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example 1

```
SFR             ;(SXM = 0)
```

Example 2

```
SFR             ;(SXM = 1)
```

Syntax SFSM

Operands None

Execution (PC) + 1 → PC
1 → FSM status bit in status register ST1

Affects FSM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	1	1	1

Description The SFSM instruction sets the FSM status bit to logic one. In this mode, an external FSR pulse is required for a receive operation, and an external FSX pulse is required if TXM = 0. If TXM = 1, FSX pulses are generated in the normal manner every time the transmit shift register XSR is loaded. See Section 3.7 for details on the operation of the serial port. FSM may also be loaded by the LST1 and RFSM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SFSM        ;FSM is set, putting the serial port in a mode
            ;of operation where frame synchronization
            ;pulses are required for each word to be
            ;transmitted or received.
```

Syntax [*label*] SHM

Operands None

Execution (PC) + 1 → PC
1 → HM status bit in status register ST1

Affects HM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	1	0	0	1

Description The SHM instruction halts internal execution when acknowledging an active HOLD (HM = 1). When HM = 0, the processor may continue execution out of internal memory but puts its external interface in a high-impedance state. This bit is set to 1 by a reset.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SHM             ;HM is set
```

Syntax [*label*] SOVM

Operands None

Execution (PC) + 1 → PC
1 → overflow mode (OVM) status bit

Affects OVM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	0	0	1	1

Description The OVM status bit is set to logic one, which enables the overflow (saturation) mode. If an overflow occurs with OVM set, the overflow flag OV is set, and the accumulator is set to the largest representable 32-bit positive (7FFFFFFFh) or negative (80000000h) number according to the direction of overflow.

OVM may also be loaded by the LST and ROVM instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SOVM        ;The overflow mode bit OVM is set, enabling the
            ;overflow mode on any subsequent arithmetic
            ;operations.
```

Syntax [*label*] SPAC

Operands None

Execution PC) + 1 → PC
(ACC) – (shifted P register) → ACC

Affects OV; affected by PM and OVM.
Affects C.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	0	1	1	0

Description The contents of the P register, shifted as defined by the PM status bits, are subtracted from the contents of the accumulator. The result is stored in the accumulator. Note that SPAC is unaffected by SXM; the P register is always sign-extended.

The SPAC instruction is a subset of LTS, MPYS, and SQRS.

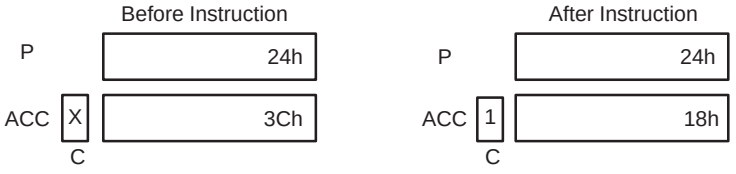
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SPAC            ;(PM = 0)
```



Syntax

Direct: [*label*] SPH *dma*
Indirect: [*label*] SPH {ind} [, *next ARP*]

Operands

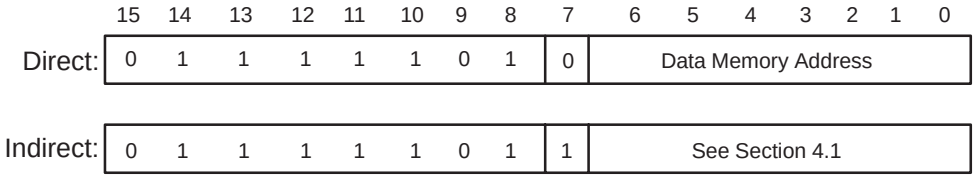
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(PR shifter output (31–16)) $\rightarrow$ dma

Affected by PM.

Encoding



Description

The high-order bits of the P register, shifted as specified by the PM bits, are stored in data memory. Neither the P register nor the accumulator are affected by this instruction. High-order bits are sign-extended when the right-shift by 6 mode is selected. Low-order bits are taken from the low P register when left-shifts are selected.

Words

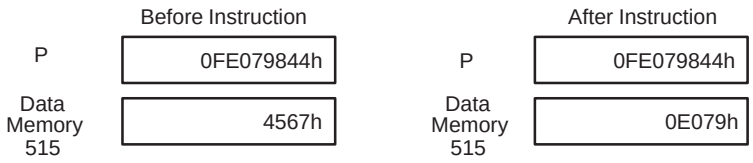
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n + nd	n+p	1 + n +nd +p	n	n + nd

Example

```
SPH   DAT3     ;(DP = 4, PM = 2)
or
SPH   *        ;If current auxiliary register contains 515.
```



Syntax

Direct: [*label*] SPL *dma*
Indirect: [*label*] SPL {ind} [, *next ARP*]

Operands

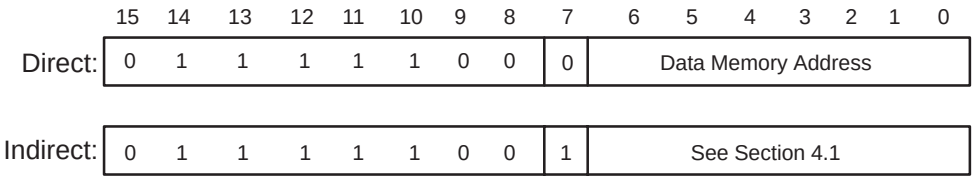
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(PR shifter output (15–0)) → dma

Affected by PM.

Encoding



Description

The low-order bits of the P register, shifted as specified by the PM bits, are stored in data memory. Neither the P register nor the accumulator are affected by this instruction. High-order bits are taken from the high P register when the right-shift by 6 mode is selected. Low-order bits are zero-filled when left-shifts are selected.

Words

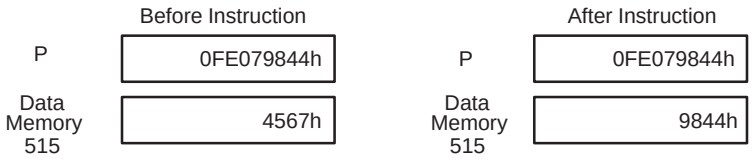
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

Example

```
SPL   DAT3     ;(DP = 4, PM = 2)
or
SPL   *        ;If current auxiliary register contains 515.
```



Syntax [*label*] SPM *constant*

Operands $0 \leq \text{constant} \leq 3$

Execution (PC) + 1 → PC
Constant → product register shift mode (PM) status bits

Affects PM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	0	1	0	PM	

Description The two low-order bits of the instruction word are copied into the PM field of status register ST1. The PM status bits control the P register output shifter. This shifter has the ability to shift the P register output either one or four bits to the left or six bits to the right, or to perform no shift. The bit combinations and their meanings are shown below.

PM	ACTION
00	No shift of multiplier output
01	Output left-shifted 1 place and zero-filled
10	Output left-shifted 4 places and zero-filled
11	Output right-shifted 6 places, sign-extended; LSB bits lost.

The left-shifts allow the product to be justified for fractional arithmetic. The right-shift by six bits has been incorporated to implement up to 128 multiply–accumulate processes without the possibility of overflow occurring. PM may also be loaded by an LST1 instruction.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
SPM   3       ;Product register shift mode 3 is selected,
              ;causing all subsequent transfers from the
              ;product register to the ALU to be shifted
              ;to the right six places.
```

Syntax

Direct: [*label*] SQRA *dma*
Indirect: [*label*] SQRA {ind} [, *next ARP*]

Operands

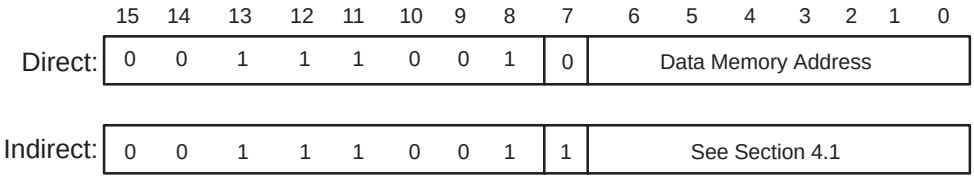
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC) + (shifted P register) → ACC
(dma) → T register
(dma) × (dma) → P register

Affects OV; affected by PM and OVM.
Affects C.

Encoding



Description

The contents of the P register, shifted as defined by the PM status bits, are added to the accumulator. The addressed data memory value is then loaded into the T register, squared, and stored in the P register.

Words

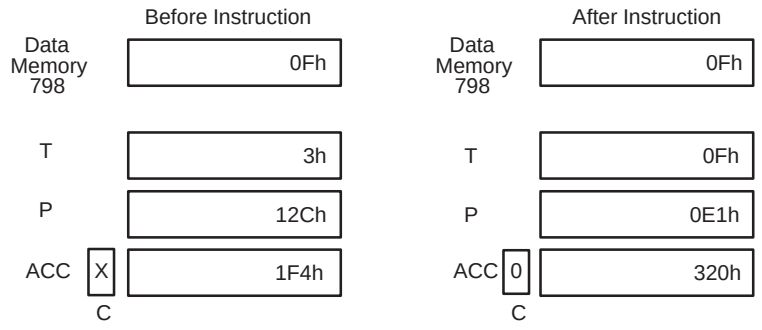
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SQRA  DAT30    ;(DP = 6, PM = 0)
or
SQRA  *        ;If current auxiliary register contains 798.
```



Syntax

Direct: [*label*] SQRS *dma*
Indirect: [*label*] SQRS {ind} [, *next ARP*]

Operands

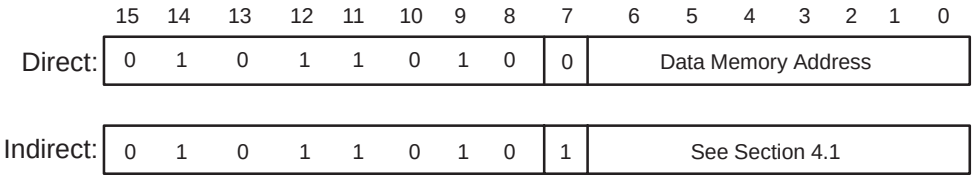
$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC) – (shifted P register) → ACC
(dma) → T register
(dma) × (dma) → P register

Affects OV; affected by PM and OVM.
Affects C.

Encoding



Description

The contents of the P register, shifted as defined by the PM status bits, are subtracted from the accumulator. The addressed data memory value is then loaded into the T register, squared, and stored into the P register.

Words

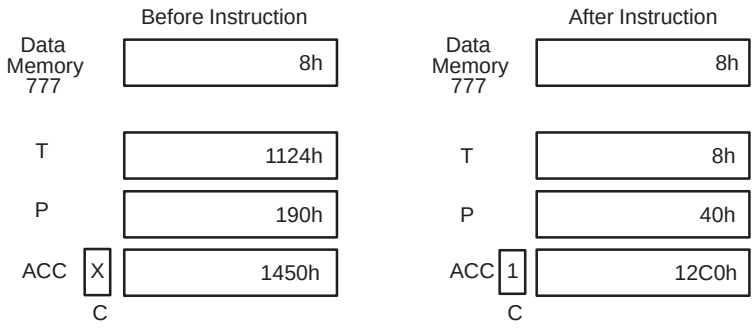
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SQRS  DAT9     ;(DP = 6, PM = 0)
```
or
```
SQRS  *        ;If current auxiliary register contains 777.
```



Syntax

Direct: [*label*] SST *dma*
Indirect: [*label*] SST {ind} [, *next ARP*]

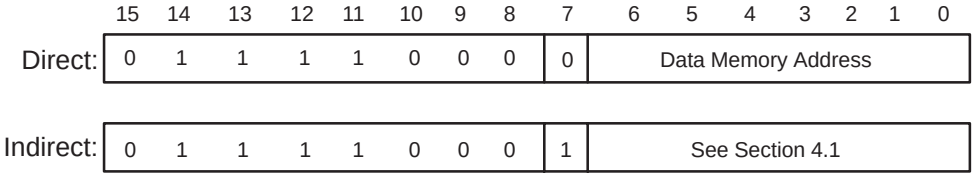
Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(status register ST0) → dma

Encoding

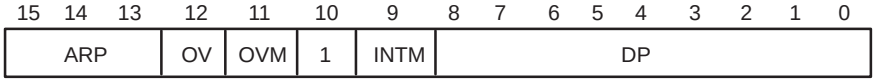


Description

Status register ST0 is stored in data memory.

In the direct addressing mode, status register ST0 is always stored in page 0, regardless of the value of the DP register. The processor automatically forces the page to be 0, and the specific location within that page is defined in the instruction. Note that the DP register is not physically modified. This allows storage of the DP register in the data memory on interrupts, etc., in the direct addressing mode without having to change the DP. In the indirect addressing mode, the data memory address is obtained from the auxiliary register selected. (See the LST instruction for more information.)

The SST instruction can be used to store status register ST0 after interrupts and subroutine calls. The ST0 contains the status bits: OV (overflow flag), OVM (overflow mode), INTM (interrupt mode), ARP (auxiliary register pointer), and DP (data memory page pointer). The status bits are stored in the data memory word as follows:



Note that SST * may be used to store status register ST0 anywhere in data memory, while SST in the direct addressing mode is forced to page 0.

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

Example

```
SST   DAT96    ;(DP = don't care)
or
SST   *        ;If current auxiliary register contains 96.
```

	Before Instruction	After Instruction
Status Register STO	0A408h	0A408h
Data Memory 96	0Ah	0A408h

Syntax

```
Direct:     [ label ]    SST1   dma
Indirect :  [ label ]    SST1   {ind} [, next ARP ]
```

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(status register ST1) → dma

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	0	1	1	1	1	0	0	1	0	Data Memory Address						
Indirect:	0	1	1	1	1	0	0	1	1	See Section 4.1						

Description

Status register ST1 is stored in data memory. In the direct addressing mode, status register ST1 is always stored in page 0, regardless of the value of the DP register. The processor automatically forces the page to be 0, and the specific location within that page is defined in the instruction. Note that the DP register is not physically modified. This allows the storage of the DP in the data memory on interrupts, etc., in the direct addressing mode without having to change the DP. In the indirect addressing mode, the data memory address is obtained from the auxiliary register selected. (See the LST1 instruction for more information.)

SST1 is used to store status bits after interrupts and subroutine calls. ST1 contains the status bits: ARB (auxiliary register pointer buffer), CNF (RAM configuration control), TC (test/control), SXM (sign-extension mode), XF (external flag), FO (serial port format), TXM (transmit mode), and the PM (product register shift mode). ST1 on the TMS320C2x also contains the status bits: C (carry) bit, HM (hold mode), and FSM (frame synchronization mode). The bits loaded into status register ST1 from the data memory word are as follows:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARB			CNF †	TC	SXM	C	1	1†	HM	FSM	XF	FO	TXM	PM	

† On the TMS320C26, bits 12 and 7 hold CNF0 and CNF1, respectively (see the CONF instruction for decoding).

Note that SST1 * may be used to store status register ST1 anywhere in data memory, while SST1 in the direct addressing mode is forced to page 0.

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1+d	1+p	2+d+p	1	1+d
Cycle Timings for a Repeat Execution					
n	n+nd	n+p	1+n+nd+p	n	n+nd

Example

```
SST1  DAT97    ;(DP = don't care)
or
SST1  *        ;If current auxiliary register contains 97.
```

	Before Instruction	After Instruction
Status Register ST1	0A7E0h	0A7E0h
Data Memory 97	0Bh	0A7E0h

Syntax [*label*] SSXM

Operands None

Execution (PC) + 1 → PC
1 → SXM status bit in status register ST1

Affects SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	**1**	0	0	1	1	1	0	0	0	0	0	0	1	1	1

Description The SSXM instruction sets the SXM status bit to logic 1, which enables sign-extension on shifted data memory values for the following arithmetic instructions: ADD, ADDT, ADLK, LAC, LACT, LALK, SBLK, SUB, and SUBT.

In addition, SSXM affects the definition of the SFR instruction. You can load SXM with the LST1 and RSXM instructions, as well.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SSXM          ;SXM is set, enabling sign extension on
              ;subsequent instructions.
```

Syntax [*label*] STC

Operands None

Execution (PC) + 1 → PC
1 → TC test/control flag in status register ST1

Affects TC.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	1	1	0	0	1	1

Description The TC (test/control) flag in status register ST1 is set to logic one. TC may also be loaded by the LST1 and RTC instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1 + p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n + p	n	n

Example

```
STC             ;TC (test/control) flag is set to logic one.
```

Syntax [*label*] STXM

Operands None

Execution (PC) + 1 → PC
1 → TXM status bit in status register ST1

Affects TXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	**1**	0	0	1	1	1	0	0	0	1	0	0	0	0	1

Description The STXM instruction sets the TXM status bit to logic 1, which configures the serial port transmit section to a mode where the FSX pin behaves as an output. A pulse is produced on the FSX pin each time the DXR register is loaded internally. The transmission is initiated by the negative edge of this pulse. TXM may also be loaded by the LST1 and RTXM instructions. If the FSM status bit is a logic zero and serial port operation has already started, the FSX pin will be driven low if TXM = 1.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
STXM          ;TXM is set, configuring FSX as an output.
```

Syntax

Direct: [*label*] SUB *dma* [, *shift*]
Indirect: [*label*] SUB {ind} [, *shift* [*next ARP*]]

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7
$0 \le$ shift ≤ 15 (defaults to 0)

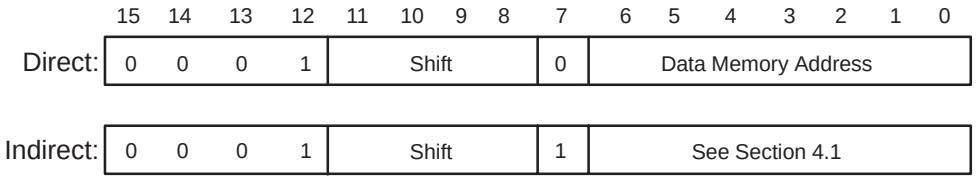
Execution

(PC) + 1 $\rightarrow$ PC
(ACC) – [(dma) $\times 2^{\text{shift}}$] $\rightarrow$ ACC

If SXM = 1:
Then (dma) is sign-extended.
If SXM = 0:
Then (dma) is not sign-extended.

Affects OV; affected by OVM and SXM.
Affects C.

Encoding



Description

The contents of the addressed data memory location are left-shifted and subtracted from the accumulator. During shifting, low-order bits are zero-filled. High-order bits are sign-extended if SXM is high and zero-filled if SXM is low. The result is stored in the accumulator.

Words

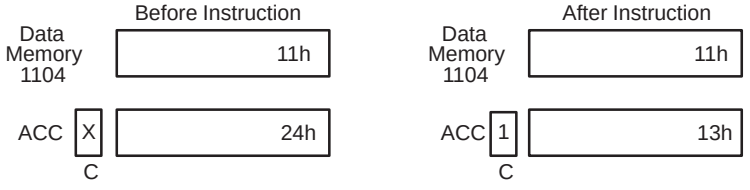
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SUB   DAT80     ;(DP = 8)
or
SUB   *         ;If current auxiliary register contains 1104.
```



Syntax

Direct: [*label*] SUBB *dma*
Indirect : [*label*] SUBB {ind} [, *next ARP*]

Operands

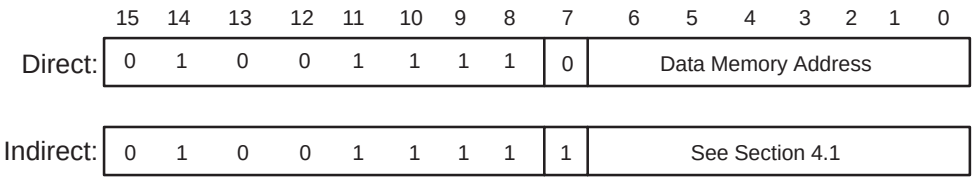
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC) – (dma) – ($\overline{C}$) → ACC

Affects C and OV; affected by OVM.

Encoding



Description

The contents of the addressed data memory location and the value of the carry bit are subtracted from the accumulator. The carry bit is then affected in the normal manner (see subsection 3.5.2).

Words

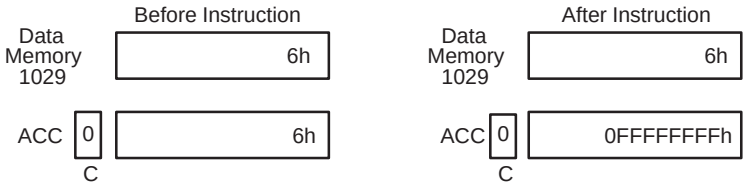
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SUBB  DAT5     ;(DP = 8)
or
SUBB  *        ;If current auxiliary register contains 1029.
```



In the above example, C is originally zeroed, presumably from the result of a previous subtract instruction that performed a borrow. The effective operation performed was 6 – 6 – ($\overline{0}$)–1, generating another borrow (and resetting carry again) in the process.

The SUBB instruction can be used in performing multiple-precision arithmetic.

Syntax

Direct: [*label*] SUBC *dma*
Indirect: [*label*] SUBC {ind} [, *next ARP*]

Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

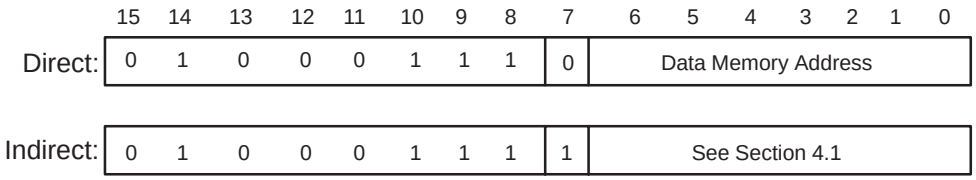
Execution

(PC) + 1 $\rightarrow$ PC
(ACC) – [(dma) $\times 2^{15}$] $\rightarrow$ ALU output

If ALU output ≥ 0:
Then (ALU output) $\times 2 + 1 \rightarrow$ ACC;
Else (ACC) $\times 2 \rightarrow$ ACC.

Affects OV.
Affects C.
Not affected by OVM (no saturation); is affected by SXM.

Encoding



Description

The SUBC instruction performs conditional subtraction, which may be used for division. The 16-bit numerator is placed in the low accumulator, and the high accumulator is zeroed. The denominator is in data memory. SUBC is executed 16 times for 16-bit division. After completion of the last SUBC, the quotient of the division is in the lower-order 16-bit field of the accumulator, and the remainder is in the high-order 16 bits of the accumulator. SUBC provides the normally expected results for division when both the denominator and numerator are positive. The denominator is affected by the SXM bit. If SXM=1, then the denominator must have a 0 value in the MSB. If SXM=0, then any 16-bit denominator value will produce the expected results. The numerator, which is in the accumulator, must initially be positive (that is, bit 31 must be 0) and must remain positive following the accumulator shift, which occurs during the SUBC operation.

If the 16-bit numerator contains less than 16 significant bits, the numerator may be placed in the accumulator left-shifted by the number of leading nonsignificant zeroes. The number of executions of SUBC is reduced from 16 by that number. One leading zero is always significant.

Note that SUBC affects OV but is *not* affected by OVM, and therefore the accumulator does not saturate upon positive or negative overflows when this instruction is executed.

Words

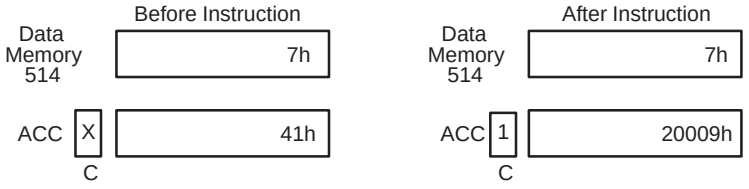
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
RPTK  15
SUBC  DAT2     ;(DP = 4)
or
RPTK  15
SUBC  *        ;If current auxiliary register contains 514.
```



Syntax

Direct: [*label*] SUBH *dma*
Indirect: [*label*] SUBH {ind} [, *next ARP*]

Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 $\rightarrow$ PC
(ACC) – [(dma) $\times 2^{16}$] $\rightarrow$ ACC

Affects OV; affected by OVM
Affects C.

Encoding

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Direct:	0	1	0	0	0	1	0	0	0	Data Memory Address						
Indirect:	0	1	0	0	0	1	0	0	1	See Section 4.1						

Description

The contents of the addressed data memory location are subtracted from the upper 16 bits of the accumulator. The 16 low-order bits of the accumulator are unaffected. The result is stored in the accumulator. The carry bit C on the TMS320C2x is reset if the result of the subtraction generates a borrow; otherwise, C is unaffected.

The SUBH instruction can be used for performing 32-bit arithmetic.

Words

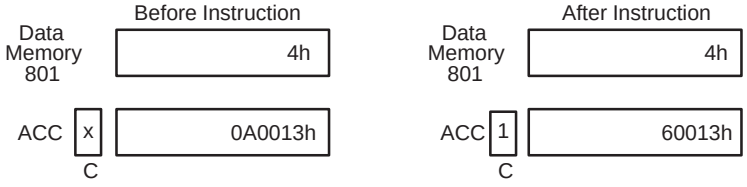
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SUBH  DAT33    ;(DP = 6)
or
SUBH  *        ;If current auxiliary register contains 801.
```



Syntax [*label*] SUBK *constant*

Operands $0 \leq$ constant ≤ 255

Execution (PC) + 1 → PC
(ACC) – 8-bit positive constant → ACC

Affects C and OV: affected by OVM.
Not affected by SXM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	0	1	8-Bit Constant							

Description The 8-bit immediate value is subtracted, right-justified, from the accumulator with the result replacing the accumulator contents. The immediate value is treated as an 8-bit positive number, regardless of the value of SXM.

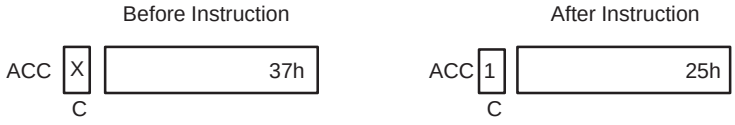
Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
SUBK  12h
```



Syntax

Direct: [*label*] SUBS *dma*
Indirect: [*label*] SUBS {ind} [, *next ARP*]

Operands

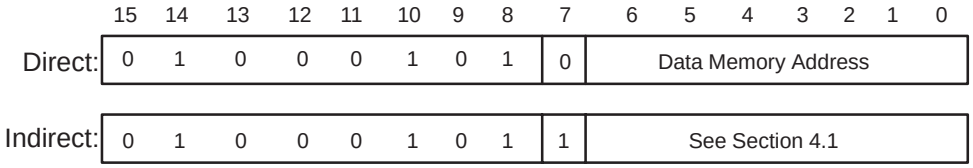
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC) – (dma) → ACC

Affects OV; affected by OVM.
Affects C.
Not affected by SXM.

Encoding



Description

The contents of the addressed data memory location are subtracted from the accumulator with sign-extension suppressed. The data is treated as a 16-bit unsigned number, regardless of SXM. The accumulator behaves as a signed number. SUBS produces the same result as a SUB instruction with SXM = 0 and a shift count of 0.

Words

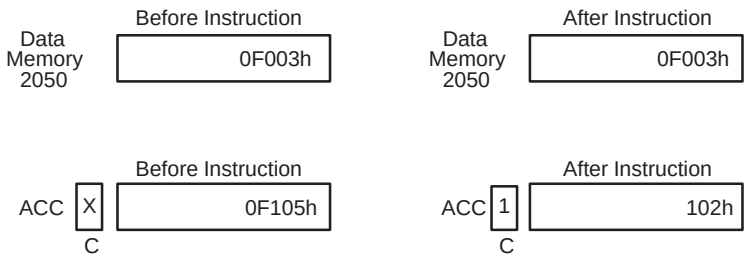
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SUBS  DAT2     ;(DP = 16)
or
SUBS  *        ;If current auxiliary register contains 2050.
```



Syntax

Direct: [*label*] SUBT *dma*
Indirect: [*label*] SUBT {ind} [, *next ARP*]

Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

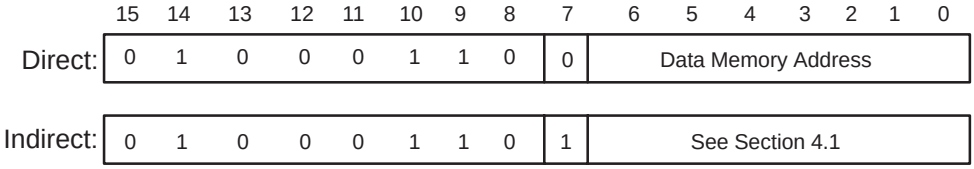
Execution

(PC) + 1 $\rightarrow$ PC
(ACC) - [(dma) $\times$ 2 $^{\text{T register (3 – 0)}}$] $\rightarrow$ (ACC)

If SXM = 1:
Then (dma) is sign-extended.
If SXM = 0:
Then (dma) is not sign-extended.

Affects OV; affected by SXM and OVM.
Affects C.

Encoding



Description

The data memory value is left-shifted and subtracted from the accumulator. The left-shift is defined by the four LSBs of the T register, resulting in shift options from 0 to 15 bits. The result replaces the accumulator contents. Sign-extension on the data memory value is controlled by the SXM status bit.

Words

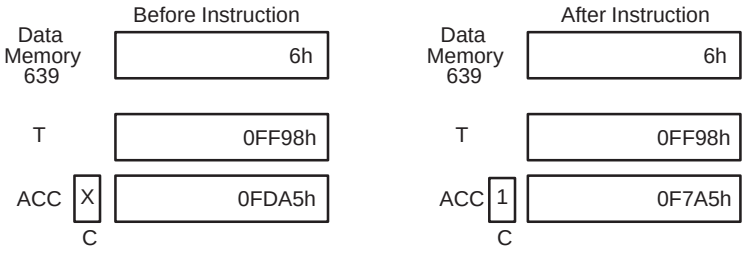
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
SUBT  DAT127   ;(DP = 4)
or
SUBT  *        ;If current auxiliary register contains 639.
```



Syntax [*label*] SXF

Operands None

Execution (PC) + 1 → PC
1 → external flag (XF) pin and status bit

Affects XF.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	**1**	0	0	1	1	1	0	0	0	0	0	1	1	0	1

Description The XF pin and the XF status bit in status register ST1 are set to logic 1. XF may also be loaded by the LST1 and RXF instructions.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
n	n	n+p	n+p	n	n

Example

```
SXF             ;The XF pin and status bit are set to logic 1.
```

Syntax

Direct: [*label*] TBLR *dma*
Indirect: [*label*] TBLR {ind} [, *next ARP*]]

Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

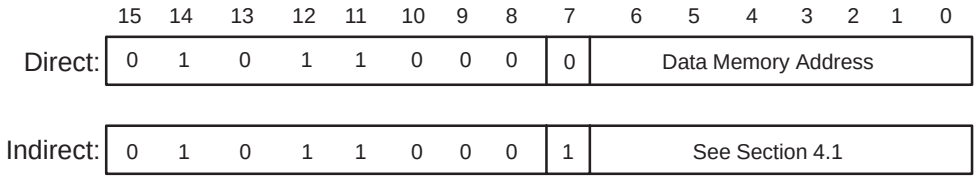
Execution

(PC) + 1 → PC
(PFC) → MCS
(ACC(15–0)) → PFC

If (repeat counter) ≠ 0:
Then (pma, addressed by PFC) → dma,
Modify AR(ARP) and ARP as specified,
(PFC) + 1 → PFC,
(repeat counter) – 1 → repeat counter.

Else (pma, addressed by PFC) → dma
Modify AR(ARP) and ARP as specified.
(MCS) → PFC

Encoding



Description

The TBLR instruction transfers a word from a location in program memory to a data memory location specified by the instruction. The program memory address is defined by the low-order 16 bits of the accumulator. For this operation, a read from program memory is performed, followed by a write to data memory. In the repeat mode, TBLR effectively becomes a single-cycle instruction, and the program counter that contains the ACCL is incremented once each cycle.

If the MP/$\overline{\text{MC}}$ pin on the TMS320C25 is low at the time of execution of this instruction and the program memory address used is less than 4096, an on-chip ROM location will be read.

Words

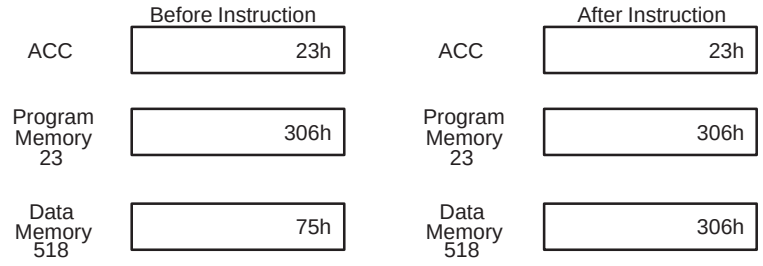
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Table in on-chip RAM:					
2	2+d	3+p	3 + d + p	3	3+d
Table in on-chip ROM:					
3	3+d	4+p	4 + d + p	4	4+d
Table in external memory:					
3+p	3+d+p	4+2p	4+d+2p	4+p	4+d+p
Cycle Timings for a Repeat Execution					
Table in on-chip RAM:					
1+n	1+n+nd	2+n+p	2+n+nd+p	2+n	2+n+nd
Table in on-chip ROM:					
2+n	2+n+nd	3+n+p	3+n+nd+p	3+n	3+n+nd
Table in external memory:					
2+n+np	1+2n+nd+np	3+n+np+p	2+2n+nd+np +p	3+n+np	2+2n+nd+np

Example

```
TBLR  DAT6      ;(DP = 4)
or
TBLR  *         ;If current auxiliary register contains 518.
```



Syntax

Direct: [*label*] TBLW *dma*
Indirect: [*label*] TBLW {ind} [, *next ARP*]

Operands

$0 \leq$ dma ≤ 127
$0 \leq$ next ARP ≤ 7

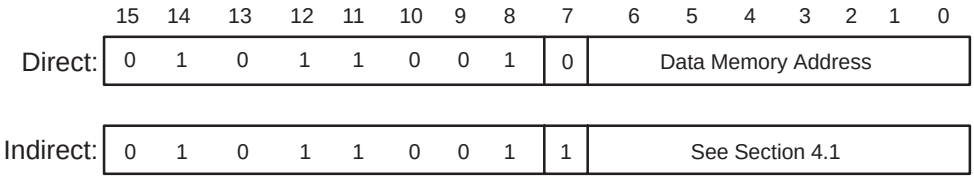
Execution

(PC) + 1 → PC
(PFC) → MCS
(ACC(15–0)) → PFC

If (repeat counter) ≠ 0:
Then dma → (pma, addressed by PFC),
Modify AR(ARP) and ARP as specified,
(PFC) + 1 → PFC,
(repeat counter) – 1 → repeat counter.

Else dma → (pma, addressed by PFC),
Modify AR(ARP) and ARP as specified.
(MCS) → PFC

Encoding



Description

The TBLW instruction transfers a word in data memory to program memory. The data memory address is specified by the instruction, and the program memory address is specified by the lower 16 bits of the accumulator. A read from data memory is followed by a write to program memory to complete the instruction. In the repeat mode, TBLW effectively becomes a single-cycle instruction, and the program counter that contains the ACCL is incremented once each cycle.

If the MP/$\overline{\text{MC}}$ pin on the TMS320C25 is low at the time of execution of this instruction and the program memory address used is less than 4096, an on-chip ROM location will be addressed but not written to.

Words

1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Table in on-chip RAM:					
2	3+d	3+p	4 + d + p	3	4+d
Table in on-chip ROM:					
not applicable					
Table in external memory:					
2+p	3 + d + p	3+2p	4+d+2p	3+p	4+d+p
Cycle Timings for a Repeat Execution					
Table in on-chip RAM:					
1+n	2+n+nd	2+n+p	3+n+nd+p	2+n	3+n+nd
Table in on-chip ROM:					
not applicable					
Table in external memory:					
1+n+np	1+2n+nd+np	2+n+np+p	2+2n+nd+np +p	2+n+np	2+2n+nd+np

Example

```
TBLW  DAT5     ;(DP = 32)
```
or
```
TBLW  *        ;If current auxiliary register contains 4101.
```

	Before Instruction		After Instruction
ACC	257h	ACC	257h
Data Memory 4101	4339h	Data Memory 4101	4339h
Program Memory 257	306h	Program Memory 257	4339h

Syntax [*label*] TRAP

Operands None

Execution (PC) + 1 → stack
30 → PC

Not affected by INTM; does not affect INTM.

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	1	1	0	0	0	0	1	1	1	1	0

Description The TRAP instruction is a software interrupt that transfers program control to program memory location 30 and pushes the program counter plus one onto the hardware stack. The instruction at location 30 may contain a branch instruction to transfer control to the TRAP routine. Putting PC + 1 onto the stack enables an RET instruction to pop the return PC (points to instruction after the TRAP) from the stack.

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
Destination on-chip RAM:					
2	2	2+p	2+p	2	2
Destination on-chip ROM:					
3	3	3+p	3+p	3	3
Destination external memory:					
3+p	3+p	3+2p	3+2p	3+p	3+p
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
TRAP        ;Control is passed to program memory location
            ;30. PC + 1 is pushed on to the stack.
```

Syntax

Direct: [*label*] XOR *dma*
Indirect: [*label*] XOR {ind} [, *next ARP*]

Operands

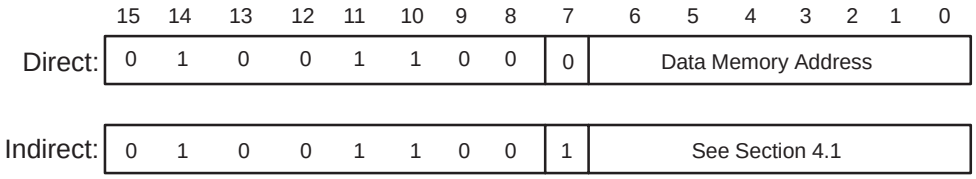
$0 \le dma \le 127$
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
(ACC(15–0)) XOR dma → ACC(15–0)
(ACC(31–16)) → ACC(31–16)

Not affected by SXM.

Encoding



Description

The low half of the accumulator is exclusive-ORed with the contents of the addressed data memory location. The upper half of the accumulator is not affected by this instruction.

Words

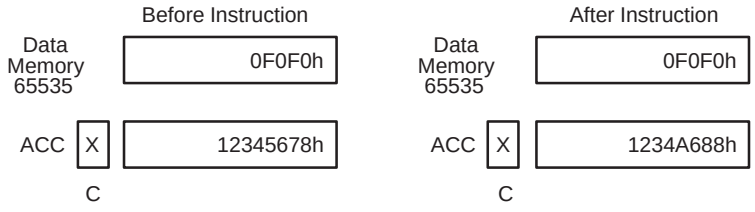
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
XOR   DAT127   ;(DP = 511)
or
XOR   *        ;If current auxiliary register contains 65535.
```



Syntax [*label*] XORK *constant* [, *shift*]

Operands
16-bit constant
0 ≤ shift ≤ 15 (defaults to 0)

Execution
(PC) + 2 → PC
(ACC(30–0)) XOR [constant × 2^{shift}] → ACC(30–0)
(ACC(31)) → ACC(31)

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	1	Shift				0	0	0	0	0	1	1	0
16-Bit Constant															

Description
The left-shifted 16-bit immediate constant is exclusive-ORed with the accumulator, leaving the result in the accumulator. Low-order bits below and high-order bits above the shifted value are treated as zeros, thus not affecting the corresponding bits of the accumulator. Note that the MSB, most significant bit, of the accumulator is not affected, regardless of the shift code value.

Words 2

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
2	2	2+2p	2+2p	2	2
Cycle Timings for a Repeat Execution					
not repeatable					

Example

```
XORK  0FFFFh,8
```

Syntax [*label*] ZAC

Operands None

Execution (PC) + 1 ≤ PC
0 ≤ ACC

Encoding

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0

Description The contents of the accumulator are replaced with zero. The ZAC instruction has been implemented as a special case of LACK. (ZAC assembles as LACK 0.)

Words 1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	1	1+p	1+p	1	1
Cycle Timings for a Repeat Execution					
not repeatable					

Example ZAC

Syntax

Direct: [*label*] ZALH *dma*
Indirect: [*label*] ZALH [{ind} [, *next ARP*]

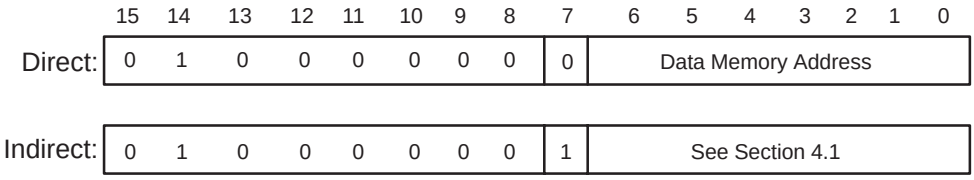
Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
0 → ACC(15–0)
(dma) → ACC(31–16)

Encoding



Description

ZALH loads a data memory value into the high-order half of the accumulator. The low-order bits of the accumulator are zeroed.

ZALH is useful for 32-bit arithmetic operations.

Words

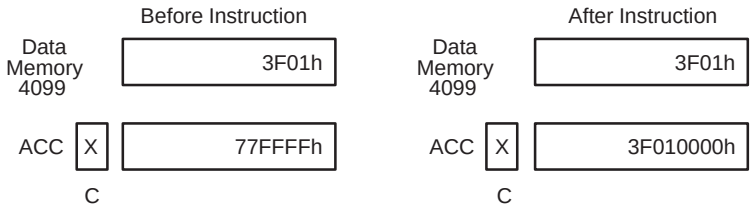
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ZALH  DAT3     ;(DP = 32)
or
ZALH  *        ;If current auxiliary register contains 4099.
```



Syntax

Direct: [*label*] ZALR *dma*
Indirect: [*label*] ZALR {ind} [, *next ARP*]

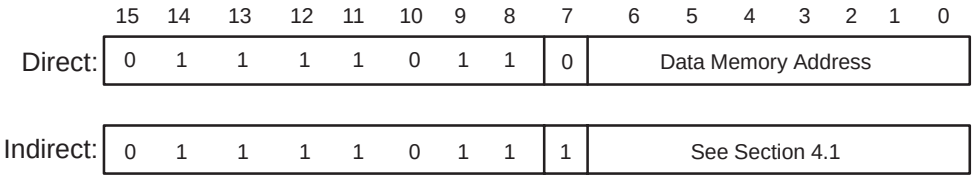
Operands

$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
8000h → ACC(15–0)
(dma) → ACC(31–16)

Encoding



Description

The ZALR instruction loads a data memory value into the high-order half of the accumulator and rounds the value by adding 1/2 LSB; that is, the 15 low bits (bits 0 –14) of the accumulator are set to zero, and bit 15 of the accumulator is set to one.

ZALR is a derivative instruction from ZALH.

Words

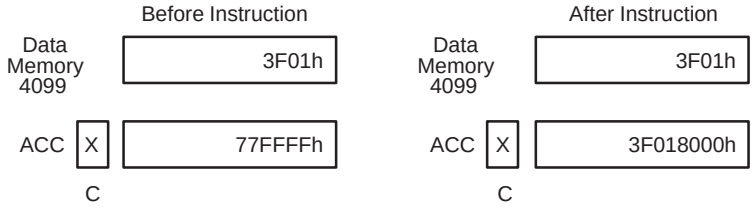
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ZALR  DAT3     ;(DP = 32)
or
ZALR  *        ;If current auxiliary register contains 4099.
```



Syntax

Direct: [*label*] ZALS *dma*
Indirect: [*label*] ZALS {ind} [*next ARP*]

Operands

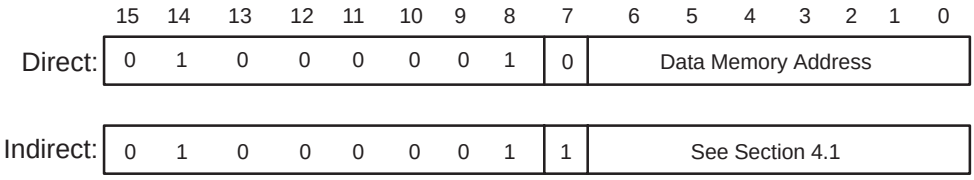
$0 \le$ dma ≤ 127
$0 \le$ next ARP ≤ 7

Execution

(PC) + 1 → PC
0 → ACC(31–16)
(dma) → ACC(15–0)

Not affected by SXM.

Encoding



Description

The contents of the addressed data memory location are loaded into the 16 low-order bits of the accumulator. The upper half of the accumulator is zeroed. The data is treated as a 16-bit unsigned number rather than a 2s-complement number. Therefore, there is no sign-extension with this instruction, regardless of the state of SXM. (ZALS behaves the same as a LAC instruction with no shift, and SXM = 0.)

ZALS is useful for 32-bit arithmetic operations.

Words

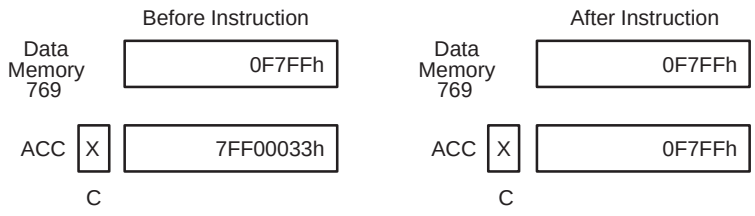
1

Cycles

Cycle Timings for a Single Instruction					
PI/DI	**PI/DE**	**PE/DI**	**PE/DE**	**PR/DI**	**PR/DE**
1	2+d	1+p	2+d+p	1	2+d
Cycle Timings for a Repeat Execution					
n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd

Example

```
ZALS  DAT1     ;(DP = 6)
```
or
```
ZALS  *        ;If current auxiliary register contains 769.
```



Chapter 5

Software Applications

The TMS320C2x microprocessor/microcomputer design emphasizes overall speed, communication, and flexibility. Many instructions are tailored to digital signal processing tasks and provide single-cycle multiply/accumulates, adaptive filtering support, and many other features. General-purpose instructions support floating-point, extended-precision, logical processing, and control applications.

This chapter provides explanations of how to use the various TMS320C2x processor and instruction set features along with assembly language coding examples. More information about specific applications can be found in the book, *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A).

The assembly source code examples in this chapter contain directives and commands specific to the Texas Instruments Assembly Language Tools. Publication *TMS320 Fixed-Point DSP Assembly Language Tools* (literature number SPRU018B) is highly recommended as a reference.

The TMS320C26 is similar to the TMS320C25 except for its internal memory configuration. This is discussed in Section 3.4 and in Appendix B.

Topics in this chapter include:

Topic **Page**

5.1 Processor Initialization 5-2
5.2 Program Control 5-22
5.3 Interrupt Service Routine 5-29
5.4 Memory Management 5-33
5.5 Fundamental Logical and Arithmetic Operations 5-43
5.6 Advanced Arithmetic Operations 5-46
5.7 Application-Oriented Operations 5-68

5.1 Processor Initialization

Prior to the execution of a digital signal processing algorithm, it is necessary to initialize the processor. Generally, initialization takes place anytime the processor is reset.

When reset is activated by applying a low level voltage to the $\overline{RS}$ (reset) input for at least three cycles, the TMS320C2x terminates execution and forces the program counter (PC) to zero. Program memory location 0 normally contains a B (branch) instruction to direct program execution to the system initialization routine. The hardware reset also initializes various registers and status bits.

After reset, the processor should be initialized to meet the requirements of the system. Instructions should be executed that set up operational modes, memory pointers, interrupts, and the remaining functions necessary to meet system requirements.

To configure the processor after reset, the following internal functions should be initialized:

- Memory-mapped registers
- Interrupt structure
- Mode control (OVM, SXM, FO, TXM, PM; plus HM and FSM on TMS320C25)
- Memory control (CNF)
- Auxiliary registers and the auxiliary register pointer (ARP)
- Data memory page pointer (DP)

The OVM (overflow mode), TC (test/control flag), and IMR (interrupt mask register) bits are not initialized by reset. The auxiliary register pointer (ARP), auxiliary register pointer buffer (ARB), and data memory page pointer (DP) are also not initialized by reset.

Example 5–1, and Example 5–2 show coding for initializing the TMS320C25, and TMS320C26, respectively, to the following machine state, in addition to the initialization performed during the hardware reset:

- All interrupts enabled
- OVM disabled
- DP set to zero
- ARP set to seven (TMS320C25 and TMS320C26)
- Internal memory filled with zeros

Example 5–1.Processor Initialization (TMS320C25)

```
       .title 'PROCESSOR INITIALIZATION'
       .def   RESET,INT0,INT1,INT2
       .def   TINT,RINT,XINT,USER
       .ref   ISR0,ISR1,ISR2
       .ref   TIME,RCV,XMT,PROC
                     *
* PROCESSOR INITIALIZATION FOR THE TMS320C25.
* RESET AND INTERRUPT VECTOR SPECIFICATION.
* BRANCHES FOR EXTERNAL AND INTERNAL INTERRUPTS.
*
      .sect "vectors"
RESET  B      INIT              ; RS- BEGINS PROCESSING HERE.
*
INT0   B      ISR0              ; INT0-  BEGINS PROCESSING HERE.
INT1   B      ISR1              ; INT1-  BEGINS PROCESSING HERE.
INT2   B      ISR2              ; INT2-  BEGINS PROCESSING HERE.
*
       .space (18h-($-RESET))*16
TINT   B      TIME              ; TIMER INTERRUPT PROCESSING.
RINT   B      RCV               ; SERIAL PORT RECEIVE PROCESSING.
XINT   B      XMT               ; SERIAL PORT TRANSMIT PROCESSING.
*
USER   B      PROC              ; TRAP VECTOR PROCESSING BEGINS.
*
* THE BRANCH INSTRUCTION AT PROGRAM MEMORY LOCATION 0 DIRECTS EXECUTION TO BEGIN
* HERE  FOR  RESET  PROCESSING  THAT  INITIALIZES  THE  PROCESSOR.  WHEN  RESET  IS
* APPLIED,THE  FOLLOWING  CONDITIONS  ARE  ESTABLISHED  FOR  THE  STATUS  AND  OTHER
* INTERNAL   REGISTERS:
*
*         ARP    OV     OVM     1     INTM      DP
*  ST0:   XXX     0       X      1      1     XXXXXXXXX
*
*        ARB   CNF    TC    SXM  C     11    HM    FSM    XF    FO   TXM    PM
*  ST1:  XXX    0     X     1    1     11     1     1     1     0    0     00
*
*   REGISTER      ADDRESS            DATA
*     DRR          0000h       XXXX XXXX XXXX XXXX
*     DXR          0001h       XXXX XXXX XXXX XXXX
*     TIM          0002h       1111 1111 1111 1111
*     PRD          0003h       1111 1111 1111 1111
*     IMR          0004h       1111 1111 11XX XXXX
*     GREG         0005h       1111 1111 0000 0000
*
*      RESERVED  XINT   RINT    TINT  INT2   INT1   INT0
* MR: 1111111111  X      X       X     X      X      X

*
      .text
INIT  ROVM                      ; DISABLE OVERFLOW MODE.
      LDPK   0                  ; POINT DP REGISTER TO DATA PAGE 0.
      LARP   7                  ; POINT TO AUXILIARY REGISTER 7.
      LACK   3Fh                ; LOAD ACCUMULATOR WITH 3Fh.
      SACL   4                  ; ENABLE ALL INTERRUPTS VIA IMR.
*
* INTERNAL DATA MEMORY INITIALIZATION.
*
```

```
      ZAC                       ; ZERO THE ACCUMULATOR.
      LARK   AR7,60h            ; POINT TO BLOCK B2.
      RPTK   31
      SACL   *+                 ; STORE ZERO IN ALL 32 LOCATIONS.
*
      LRLK   AR7,200h           ; POINT TO BLOCK B0.
      RPTK   255
      SACL   *+                 ; ZERO ALL OF PAGES 4 AND 5.
*
      LRLK   AR7,300h           ; POINT TO BLOCK B1.
      RPTK   255
      SACL   *+                 ; ZERO ALL OF PAGES 6 AND 7.
*
*  THE  PROCESSOR  IS  INITIALIZED.  THE  REMAINING  APPLICATION-DEPENDENT  PART  OF
*  THE SYSTEM (BOTH ON- AND OFF-CHIP) SHOULD NOW BE INITIALIZED.

*
       EINT                     ; ENABLE ALL INTERRUPTS.
```

Example 5–2.Processor Initialization (TMS320C26)

```
       .title    'INIT26'
       .title    'TMS320C26 PROCESSOR INITIALIZATION'
       .width    100
       .option   ×
       .def      RESET,INT0,INT1,INT2
       .def      TINT,RINT,XINT,USER
       .ref      ISR0,ISR1,ISR2
       .ref      TIME,RCV,XMT,PROC
*
*   RESET AND INTERRUPT VECTOR SPECIFICATION:
    BRANCHES FOR EXTERNAL AND INTERNAL INTERRUPTS
*
*
RESET  B   INIT                  ; RS- will begin processing here
*
INT0   B   ISR0                  ; INT0– PROCESSING
INT1   B   ISR1                  ; INT1– PROCESSING
INT2   B   ISR2                  ; INT2– PROCESSING
       .space 16*16              ; RESERVED TIME
TINT   B   TIME                  ; TIMER INTERRUPT PROCESSING
RINT   B   RCV                   ; SERIAL PORT RECEIVE PROCESSING
XINT   B   XMT                   ; SERIAL PORT TRANSMIT PROCESSING
USER   B   PROC                  ; TRAP VECTOR PROCESSING
*

*   THE BRANCH INSTRUCTION AT LOCATION 0 DIRECTS EXECUTION TO BEGIN HERE FOR
RESET
*   PROCESSING TO INITIALIZE THE PROCESSOR. WHEN RESET IS APPLIED, THE FOLLOW-
ING
*   CONDITIONS ARE ESTABLISHED FOR THE STATUS AND OTHER INTERNAL REGISTER.
*

*   IN THIS EXAMPLE THE BRANCH INCLUDES THAT THE ARP IS SET TO 7.

*   THE AUXILIARY REGISTIER POINTER IS NOT SET FROM RESET.

*
```

```
*         ARP    OV    OVM     1    INTM      DP
* ST0:    111    0      X      1     1     XXXXXXXXX
*
*  ARB   CNF0   TC    SXM    C    1    CNF1   HM    FSM    XF    F0   TXM    PM
*  ST1:  XXX    X     1     1    1     0     1     1     1     0    0     00
*
*   REGISTER      ADDRESS            DATA
*     DRR          0000h        XXXX XXXX XXXX XXXX
*     DXR          0001h        XXXX XXXX XXXX XXXX
*     TIM          0002h        1111 1111 1111 1111
*     PRD          0003h        XXXX XXXX XXXX XXXX
*     IMR          0004h        1111 1111 11XX XXXX
*     GREG         0005h        1111 1111 0000 0000
*
*      RESERVED  XINT   RINT    TINT  INT2   INT1   INT0
IMR: 1111111111   X      X       X     X      X     X
*
       def      INIT
B0     .set   0200h             ; DATA MEMORY BLOCK B0
B2     .set   0060H             ; DATA MEMORY BLOCK B2
IMR    .set   4                 ; INTERRUPT MASK REGISTER
       .TEXT
INIT   ROVM                     ; DISABLE OVERFLOW MODE
       LDPK   0                 ; POINT TO DATA MEMORY PAGE 0
       LARP   7                 ; POINT TO AUXILIARY REGISTER 7
       CONF   0                 ; CONFIGURE ALL INTERNAL RAM
                                ; BLOCKS AS DATA MEMORY
       LACK   03FH              ; LOAD ACCUMULATOR WITH INTERRUPT MASK
       SACL   IMR               ; ENABLE ALL INTERRUPTS
*
*      INTERNAL DATA MEMORY INITIALIZATION
*
       .sect  "INIT_RAM"
       ZAC                      ; ZERO THE ACCUMULATOR
       LARK   AR7,B2            ; POINT TO BLOCK B2
       RPTK   31
       SACL   *+                ; STORE ZERO IN ALL 32 LOCATIONS
*
       LRLK   AR7,B0            ; POINT TO BLOCK B0
       LARK   AR6,5             ; REPEAT LOOP1 6 TIMES
LOOP1: RPTK   255               ; ZEROING BLOCK B0, B1 AND B3
       SACL   *+                ; ZERO THE PAGES: 4–15
       LARP   AR6
       BANZ   LOOP1,*–,AR7      ; REPEAT 6 TIMES
*
*   THE PROCESSOR IS INITIALIZED. THE REMAINING APPLICATION DEPENDENT PART OF THE
    SYSTEM (BOTH ON- AND OFF-CHIP) SHOULD NOW BE INITIALIZED.
*
       EINT                     ; ENABLE ALL INTERRUPTS
```

5.1.1 TMS320C26 Download/Bootstrapping Modes

The TMS320C26 boot program allows three types of download:

- Mode 1: parallel download from an I/O port
- Mode 2: serial download from an RS232 port
- Mode 3: external memory (EPROM) download.

Note: In all three modes,

- The download begins at data block B0 (0200h) in internal space and continues until the length specified by the download mode is reached. The appropriate memory blocks are then configured as program, and execution transfers to the first address in program block B0 (0FA00h).
- The ROM interrupt vector table uses AR modification. To save context on an interrupt, the user-defined vector table in program block B0 should not modify the auxiliary registers. This is especially important in external global memory downloads in which an unmodified B(ranch) instruction is used to identify valid code.
- If the $\overline{RS}$ signal is not a clean TTL signal, the various processor sections may not be properly synchronized with each other. This is because the $\overline{RS}$ pin does not have an internal Schmidt trigger built into it. It is therefore recomended that you use a Schmidt-triggered gate with an RC time constant and external switch to avoid this.

5.1.1.1 Mode 1: Parallel Download From an I/O Port

You can perform a parallel download through a parallel interface to a host processor via parallel I/O port zero (PA0). Both 8- and 16-bit wide data words can be transferred. $\overline{BIO}$ and XF are used as handshake signals to the host.

If the $\overline{BIO}$ signal is low at reset, a parallel I/O mode download will be initiated. Otherwise, bootloader control passes to modes 2 and 3. The BIOZ ($\overline{BIO}$ pin) test is made 36+2d cycles after reset, but it is recommended that the $\overline{BIO}$ pin be initialized at power-up or reset. The value of *d* is the number of wait states used at global memory address 08000h. In this case, a read of memory location 08000h is used as a delay and is part of the global EPROM download option. However, the status of that test is not used until after the $\overline{BIO}$ pin has been polled.

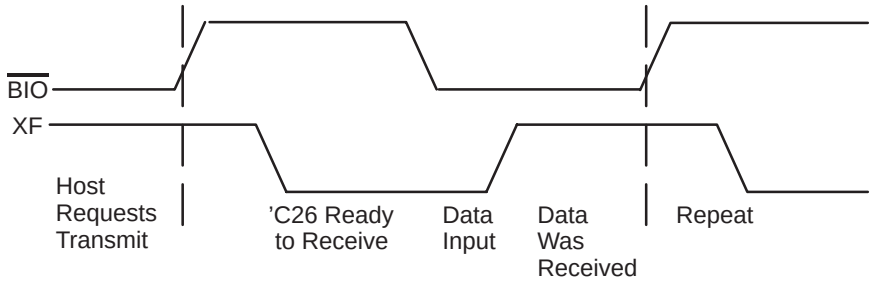
Each transfer of program data from the host is accomplished through a $\overline{BIO}$ and XF handshake with the host. A data transfer is initiated by the host, driving

the $\overline{BIO}$ pin low. When the $\overline{BIO}$ pin goes low, the C26 inputs the data from port address zero and stores it in the currently available memory location. The C26 then drives the XF pin high to indicate to the host that the data has been received. The C26 then waits for the $\overline{BIO}$ pin to go high before setting the XF pin low. The low status of the XF line can then be polled by the host to indicate that the C26 is ready for another piece of data.

Example 5–3. BIO–XF Transfer Protocol

```
BIO low    ;at reset initiates parallel I/O mode
;------------------------------------------------------
BIO high   ;host requests to transmit
XF  low    ;C26 indicates ready to receive
BIO low    ;host indicates data valid; C26 inputs STATUS
XF  high   ;C26 indicates word was received
BIO high   ;host requests to transmit
XF  low    ;C26 indicates ready to receive
BIO low    ;host indicates data valid; C26 inputs INTERRUPT
XF  high   ;C26 indicates word was received
BIO high   ;host requests to transmit
XF  low    ;C26 indicates ready to receive
  : :      ;
  : :      ;This is repeated as many times as needed
  : :      ;
BIO high   ;host requests to transmit
XF  low    ;C26 indicates ready to receive
BIO low    ;host indicates data valid; C26 inputs CHECKSUM
XF/PA0     ;C26 indicates CHECKSUM status; HIGH=pass LOW=fail
;------------------------------------------------------
; Synchronization word
;------------------------------------------------------
BIO high   ;host requests transmit
XF  low    ;C26 indicates ready to receive
BIO low    ;C26 branches to execute program (data input
            but not used)
BRANCH PROG;program is now running
```

Figure 5–1. BIO–XF Handshake



Note: The falling edge of $\overline{BIO}$ acts like a latch, causing the C26 to input the data.

Figure 5–2. Sequence for 8-Bit Transfers

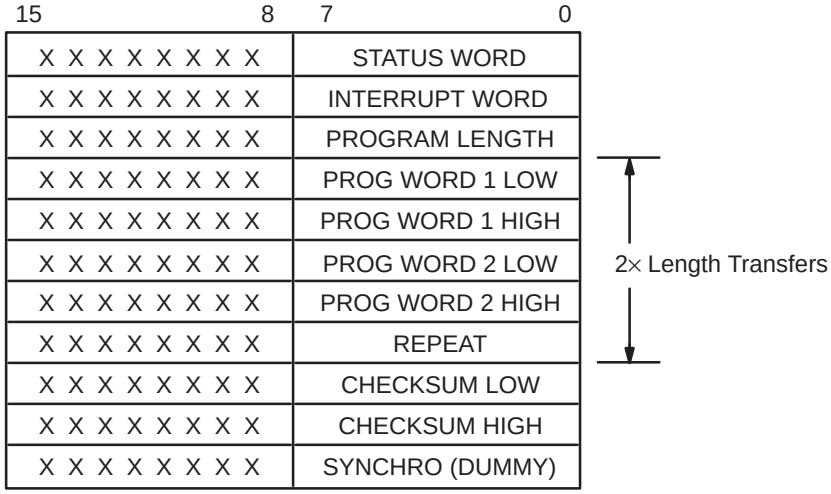
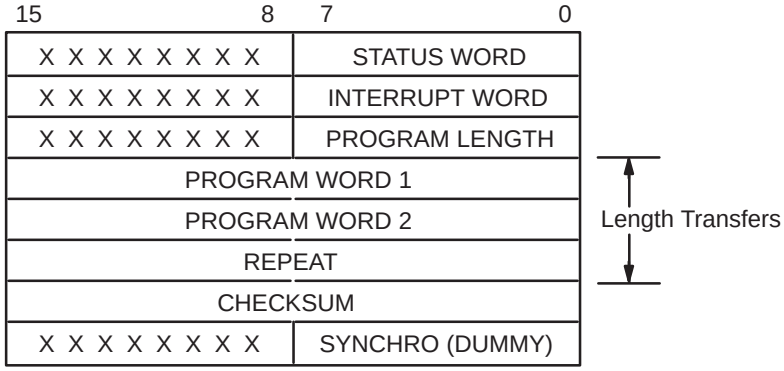

15
8
7
0
X X X X X X X X
STATUS WORD
X X X X X X X X
INTERRUPT WORD
X X X X X X X X
PROGRAM LENGTH
X X X X X X X X
PROG WORD 1 LOW
X X X X X X X X
PROG WORD 1 HIGH
X X X X X X X X
PROG WORD 2 LOW
X X X X X X X X
PROG WORD 2 HIGH
X X X X X X X X
REPEAT
X X X X X X X X
CHECKSUM LOW
X X X X X X X X
CHECKSUM HIGH
X X X X X X X X
SYNCHRO (DUMMY)
2× Length Transfers

Figure 5–3. Sequence for 16-Bit Transfers



Note: In all transfers, the XF pin can be ignored as long as the host allows sufficient time for the C26 to get ready for the next transfer.

Configuration Word Definitions

STATUS (1 $\overline{\text{BIO}}$–XF transfer)

This is the first word sent to the C26. The bit fields for this word are given below.

Bits D0, D1, D2 are the MSBs of the program length.
Bit D3 selects the reset/download mode:
0 = reset only (no download)
1 = start download of the program
Bit D4 selects the transmission/memory format:
0 = 8-bit format
1 = 16-bit format (not allowed in serial mode)
Bits D5–D7 should be set low (Do not use them.)

INTERRUPT (1 $\overline{\text{BIO}}$–XF transfer)

This word defines the interrupt and final memory configuration to be installed after bootstrapping. During the bootload process, blocks B0, B1, and B3 are configured as data and always loaded first. This word is loaded into the C26 by a single transfer with the upper bits being masked off. The configuration is as follows.

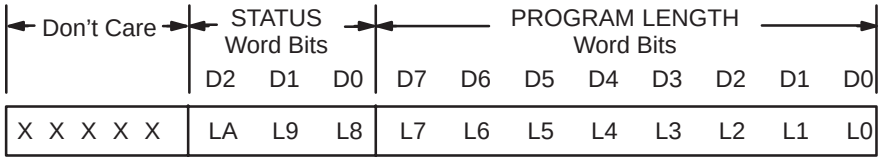
Bits D0–D5 are loaded into the interrupt mask register (IMR).
Bits D6 & D7 define the memory configuration after download:

D7	D6	Program Memory	Data Memory
0	0	B0	B1, B2, B3
0	1	B0, B1	B2, B3
1	0	B0, B1, B3	B2

PROGRAM LENGTH (1 $\overline{\text{BIO}}$–XF transfer)

The third word to be transferred is the program length, starting at block B0 (0200h) followed by B1 and B3. The 8 LSBs of the LENGTH word are combined with bits D0, D1, and D2 of the STATUS word to form the total program length (up to 2K words in length). The length does not include any of the control, CHECKSUM, or SYNCHRONIZATION words.

Figure 5–4. Building LENGTH From STATUS and PROGRAM LENGTH Words



PROGRAM WORD (1 or 2 $\overline{\text{BIO}}$–XF transfers)

The next LENGTH program words are then loaded into the internal RAM followed by external data RAM at 0800h. In the 8-bit mode, two words are transferred for each complete program word. That is, 4K transfers will result in up to 2K program words received. Also note that the maximum length can extend past the last address of block B3, into external data memory, by 512 words. In the 8-bit mode, the byte sequence is low to high.

CHECKSUM (1 or 2 $\overline{\text{BIO}}$–XF transfers)

The CHECKSUM word verifies the correct result of the transfer. The checksum is defined as the lower 16 bits of the sum of all program words transferred. The checksum does not include any control words or the final checksum sent by the host. After completing the program transfer, the host transmits a precalculated checksum, and the C26 returns the status on the XF line and port PA0. The checksum status definitions are shown below. In the 8-bit mode, the byte sequence is low to high.

XF=0 or PA0= 00h, indicates a checksum error.
XF=1 or PA0=0FFh, indicates a correct checksum.

Note: If a checksum error occurs, this will cause the normal $\overline{\text{BIO}}$–XF handshake to fail. A host timeout (loop count) can be used to verify a failed handshake and is a good method to detect a failed checksum as well.

SYNCHRONIZATION (1 $\overline{\text{BIO}}$–XF transfer)

After loading the CHECKSUM, the value previously transmitted in the configuration word reconfigures the internal memory and interrupts. The C26 then waits for a falling edge on the $\overline{\text{BIO}}$ pin before program control is passed to the first address of B0. If a checksum error has occurred, this allows the host to check the status and possibly reboot the system. When $\overline{\text{BIO}}$ goes low, program control is always passed to the first address of program block B0, regardless of the checksum status.

Note: Because the XF pin is used as a handshake signal during transfers with the host, suitable software control must verify the correct sumcheck status.

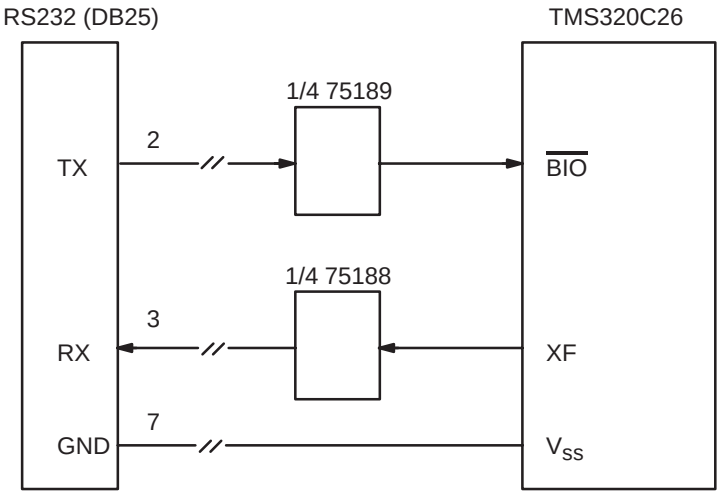
5.1.1.2 Mode 2: Serial Download From an RS232 Port (8 Data Bits, 2 Stop Bits, 1 Start Bit)

If the $\overline{\text{BIO}}$ signal is found to be high 39+2d cycles after reset, a test is made to determine if external global memory (EPROM, mode 3) is present. If this fails, a serial download is performed. It is recommended that you initialize the $\overline{\text{BIO}}$ pin at reset to avoid inadvertently selecting the wrong mode. The value of *d* is the number of wait states for global memory address 08000h and becomes part of the delay before polling the $\overline{\text{BIO}}$ pin.

The presence of an unmodified B instruction in the global data space (but **not** in normal data space) determines whether there is an external EPROM in global memory. For more information, refer to subsection 5.1.1.3.

The serial link is RS232 standard, using TTL levels at the $\overline{\text{BIO}}$ and XF pins. In this case, the $\overline{\text{BIO}}$ pin receives the data from the host via an RS232 line receiver, and the XF pin sends status back to the host via a line driver. The receive levels and data format are shown below.

Figure 5–5. RS232 Connection to the TMS320C26



C26 $\overline{\text{BIO}}$ PIN (RS232 TRANSMIT DATA 'TX')

Stop Bits = TTL logic high (1)
Start Bit = TTL logic low (0)
Data Bits = MSB received first

C26 XF PIN (RS232 RECEIVE DATA 'RX')

On reset, XF is driven high, indicating that a transfer has been initiated. If the download is not successful and the checksum fails, XF is driven low, indicating a failure. The host should wait until this time to poll the checksum verification status. The levels are given below.

Logic high (1) = Transmission in progress or checksum valid
Logic low (0) = Checksum error

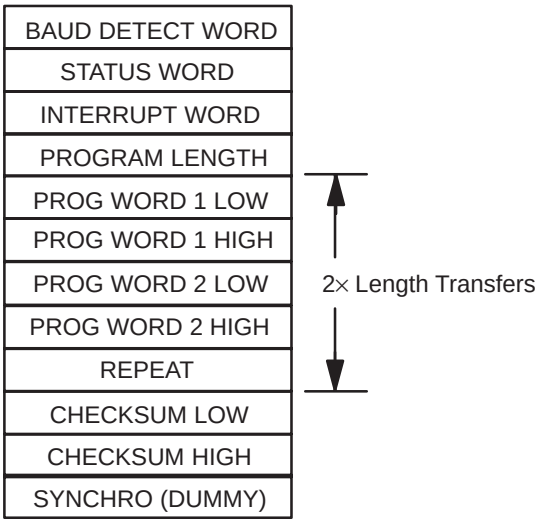
CAUTION

RS232 line levels are not TTL-compatible. RS232 line drivers and receivers, such as the Texas Instruments 75188 and 75189, must be used to interface to the RS232 level.

Example 5–4. RS232 Transfer Protocol

```
BIO high   ;at reset signals either serial or EPROM load
EPROM ?    ;Global and normal data space is checked for an EPROM
  :    :   ;signiture.  If found mode 3 download is entered.
  :    :   ;-------------------------------------------
BIO high   ;stop bit (has been high since reset)
BIO low    ;start bit, this bit is timed for baud rate
BIO DATA_7 ;high, signals end of start bit for baud rate detect
BIO DATA_6 ;rest of data bits for baud rate detect are don't care
BIO DATA_5 ;don't care
BIO DATA_4 ;don't care
BIO DATA_3 ;don't care
BIO DATA_2 ;don't care
BIO DATA_1 ;don't care
BIO DATA_0 ;don't care
BIO high   ;stop bit 1, end of baud rate detect transfer
BIO high   ;stop bit 2,
BIO low    ;start bit, begin STATUS word transfer
BIO DATA_7 ;
  :    :   ;This process is repeated until all the control words,
  :    :   ;program words and checksum have been transferred.
  :    :   ;Finally, one final word (SYNCH) is used to hold the
  :    :   ;C26 momentarily before execution of the users program.
  :    :   ;
BIO high   ;stop bit, signals end of CHECKSUM HIGH transfer
XF/PA0     ;C26 indicates CHECKSUM status HIGH=pass Low=fail
BIO low    ;C26 branches to execute program (data input but not used)
BRANCH PROG;program is now running
```

Figure 5–6. Sequence for RS232 Transfer (8 Data Bits Only)



Configuration Word Definitions

BAUD DETECT (1 RS232 transfer)

The first word transmitted by the host detects the baud rate by sampling the low period of the start bit. In this case, the stop bits have been previously holding the $\overline{BIO}$ line high, and the start bit drives the line low. The next bit is data and must be driven high. Since the data is received MSB first, the synchronization word sent to the serial port may be 1xxxxxxx. The low period of the start bit is sampled by using a software timing loop. The C26 then times out the remaining data bits (dummy bits) and waits for the next start bit ($\overline{BIO}$ going low). Note that the serial link is not interrupt driven and therefore uses all of the available processor overhead for timing the incoming data stream.

STATUS (1 RS232 transfer)

The second word sent to the C26 is the 8-bit STATUS word. The bit fields are given below.

Bits D0, D1, and D2 are the MSBs of the program length.
Bit D3 selects the reset/download mode:
- 0 = reset only (no download)
- 1 = start download of the program

Bit D4 selects the transmission/memory format:
- 0 = 8-bit format
- 1 = 16-bit format (not allowed in serial mode)

Bits D4–D7 should be set low. (Do not use them).

INTERRUPT (1 RS232 transfer)

The third word defines the interrupt and final memory configuration to be installed after bootstrapping. During the bootload process, blocks B0, B1 and B3 are configured as data and are always loaded first. This word is loaded into the C26 with a single transfer with the upper bits being masked off. The configuration is as follows.

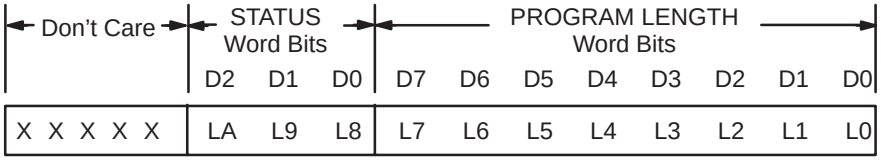
Bits D0–D5 are loaded into the interrupt mask register (IMR)
Bits D6 & D7 define the memory configuration after download

D7	D6	Program Memory	Data Memory
0	0	B0	B1, B2, B3
0	1	B0, B1	B2, B3
1	0	B0, B1, B3	B2

PROGRAM LENGTH (1 RS232 transfer)

The fourth word is the program length to be transferred starting at block B0 (0200h) followed by B1 and B3. The 8 LSBs of the LENGTH word are combined with bits D0, D1, and D2 of the STATUS word to form the total program length (up to 2K words in length). The length does not include any of the control, CHECKSUM, or SYNCHRONIZATION words.

Figure 5–7. Building LENGTH From STATUS and PROGRAM LENGTH Words



PROGRAM WORD (2 RS232 transfers each)

The next LENGTH program words are then loaded into the internal RAM followed by external data RAM at 0800h. In the RS232 mode, two words are transferred for each complete program word. That is, 4K word transfers will result in up to 2K program words received. Also note that the maximum length can extend past the last address of block B3, into external data memory, by 512 words. In the RS232 mode, the byte sequence is low to high.

CHECKSUM (2 RS232 transfers)

The CHECKSUM word is used to verify correct result of the transfer. The checksum is defined as the lower 16 bits of the sum of all program words transferred. The checksum does not include any control words or the final checksum sent by the host. After completing the program transfer, the host transmits

a precalculated checksum, and the C26 returns the status on the XF line and port PA0. The checksum status definitions are shown below. In the RS232 mode, the byte sequence is low to high.

XF=0 or PA0= 00h, indicates a checksum error.
XF=1 or PA0=0FFh, indicates a correct checksum.

SYNCHRONIZATION (1 RS232 transfer)

After loading the CHECKSUM, the value previously transmitted in the configuration word reconfigures the internal memory and interrupts. The C26 then waits for a falling edge on the $\overline{BIO}$ pin before program control is passed to the first address of B0. If a checksum error has occurred, this allows the host to check the status and possibly reboot the system. When $\overline{BIO}$ goes low, program control is always passed to the first address of program block B0, regardless of the checksum status.

Note: XF is driven high by reset and remains high to indicate that a transfer is in progress. A high level on XF also indicates that a checksum is correct. If needed, a host timeout can be used to determine if the XF status indicates a transfer is in progress or a correct checksum has been received.

5.1.1.3 Mode 3: External Memory (EPROM) Download

If the $\overline{BIO}$ signal is found to be high 39+2d cycles after reset, a test is made to determine if external global memory is present. If this fails, a serial download (mode 2) is performed. It is recommended that $\overline{BIO}$ pin be initialized at power-up or reset to avoid inadvertently selecting the wrong mode. The value of *d* is the number of wait states used at global memory address 08000h and becomes part of the delay before polling the status of $\overline{BIO}$.

The presence of an EPROM is determined by a test pattern check for an unmodified B instruction in the first download location. Both global and normal data spaces are checked. The test pattern must be found in the global data space but not in normal data space.

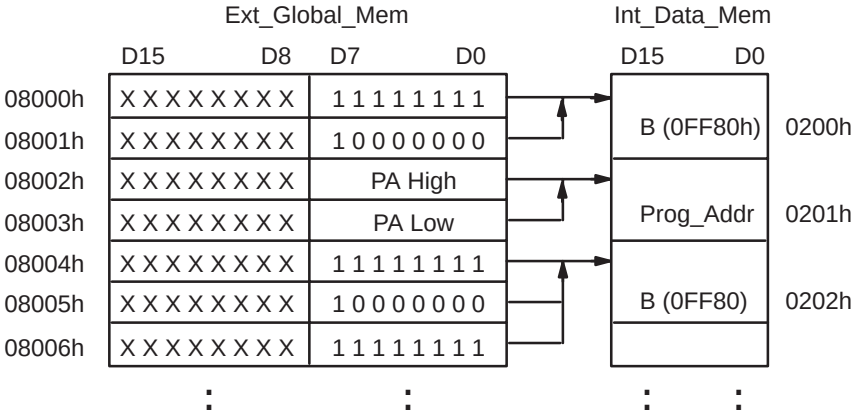
This bit pattern test was chosen because the ROM-coded vector table uses ARP modification while branching to your vector table in block B0. If your program were also to use ARP modification, the ARP buffer (ARB) would be overwritten, and ARP recovery during an interrupt service routine would not be possible. The conclusion is that the unmodified B instruction is an excellent test because you should never modify it. Furthermore, since most systems do not decode the global memory space when selecting external memory, a random bit pattern resembling an unmodified branch instruction will be rejected as a valid EPROM signature. Global memory decoding must therefore be used to download from external memory (EPROM).

It is impossible to download from an EPROM if the global memory select pin $\overline{BR}$ (bus request) is not used to enable the EPROM. The advantage of this method is that $\overline{BR}$ can also be ORed with $\overline{MSC}$ to generate a one-wait state ready condition for global memory access.

The signature test subtracts the value of a B instruction (0FF80h) from the resulting combined 16 bits of the first two words in location 08000h. If a zero is returned in the accumulator, it indicates that a branch was found. The TMS320C26 performs this test in global memory by setting GREG=080h. If a B instruction is present, it indicates that a valid EPROM may have been found. The ’C26 performs the same test in normal data space by setting GREG=0h. If a B instruction is present again, mode 3 is aborted and mode 2 (RS232 serial port) operation is entered.

The downloading then continues until all of B0, B1, and B3 are filled with data (1536 words). If additional data recovery is needed, your downloaded program can take over. The memory to be loaded is recovered from the lower 8 data bits (D0–D7) in a HI,LO,HI,LO order. The upper byte is masked out. The byte ordering for the first few words, including the test branch, is shown in Figure 5–8.

Figure 5–8. External Memory Byte Ordering



In this mode, no checksum is performed because no host connection is used to perform the download. If you still want a checksum, your program can perform this task.

Example 5–5.TMS320C26BFNL Bootloader

```
;------------------------------------------------------------;
;                                                            ;
;  TMS320C26BFNL Bootloader          1/15/92                 ;
;                                                            ;
;------------------------------------------------------------;
 .text
 .title "***  Texas Instruments  TMS320C26 Bootloader  ***"
 .mmregs
*-------------------------------------------------
MEMORY: .set 060h ;Temporary Register
LENGTH: .set 061h ;Program-Length
CHECK:  .set 062h ;Checksum
MASKFF: .set 063h ;Low-Byte-Mask
WORD8L: .set 064h ;Low-Byte Data Word
WORD8H: .set 065h ;High-Byte Data Word
BITLEN: .set 066h ;RS232 bit length
MODE:   .set 067h ;Functional mode
STATUS: .set 07Eh ;Statusword
INTER:  .set 07Fh ;Interrupt-Word
*************************************************
POSST:  .set     0Bh      ;Statusbit-Position
POSRD:  .set     0Ch      ;Reset\Downl.-Bit-Pos
BCB1:   .set     09h      ;Block-Config-Bit1-Po
BCB2:   .set     08h      ;Block-Config-Bit2-Po
ADRESS: .set     0200h    ;Data-Adress of B0
PROG:   .set     0FA00h   ;Prog-Adress of B0
EPROM:  .set     08000h   ;EPROM address
LEPROM: .set     0BFFh    ;EPROM length
*-------------------------------------------------*
*         RESET AND INTERRUPTS                     *
*-------------------------------------------------*
          B    START,*,AR7  ;Reset
          B    PROG+2,*,AR0 ;Interrupt 0
          B    PROG+4,*,AR0 ;Interrupt 1
          B    PROG+6,*,AR0 ;Interrupt 2
          .space 16 * 16    ;reserve 16 words
          B    PROG+8,*,AR0 ;Timer-Interrupt
          B    PROG+10,*,AR0;Serial-Port-Int.
          B    PROG+12,*,AR0;Serial-Port-Int.
          B    PROG+14,*,AR0;Software-Interrupt
*-------------------------------------------------*
*   DOWNLOAD PROGRAM AREA      *
*-------------------------------------------------*
GLITCH:                     ;
START     ldpk  0           ;
          rsxm              ;
          lack  0FFh        ;Clear Checksum and load Mask
          sacl  MASKFF      ;
          sach  CHECK       ;
          lark  AR1,0       ;Load AR1+1 words (last in accum)
          call  Test_Load1  ;Test GLOBAL EPROM(must return 0)
*-------------------------------------------------
```

```
*  READ FUNCTIONAL MODE 36+2d CYCLES AFTER RESET
*     BIO = 0 ---> COPROCESSOR (PARALLEL I/O) LOAD
*     BIO = 1 ---> MULTIPROCESSOR (SERIAL) MODE
*                  -OR- BYTE WIDE EPROM LOAD  <-- NEW
*-------------------------------------------------
          bioz  COPRO1       ;BIO low -> COPROCESSOR
           bnz   MULTI        ;Zero indicates B ->PASS
           lark  AR1, 0       ;if pass test NORMAL data space
           call  Test_Load2   ;
           bz    MULTI        ;Zero indicates B ->FAIL
           call  Full_Load    ;OK to load EPROM
           conf  3            ;B0, B1 & B3 as program
   ;NOP                       ;NOP adds extra latency
           B     NEED2        ;Double B for CONF 3 latency
MULTI:    ;-----------------------------------------------;
          ; MULTIPROCESSOR (SERIAL) MODE (BIO=INPUT)     ;
          ;             *** WARNING ***   ;
          ; First word must be 1 (ONE)to synchronize low ;
          ; period.  Treated as a dummy word. (Not used) ;
          ;-----------------------------------------------;
          lark   AR1,0        ;init. bitlen counter
          LACK   1            ;MODE=1 MULTIPROCESSOR/UART
AUTOBO    bioz   STBIT,*,AR1  ;wait for start bit
          b      AUTOBO       ;
STBIT     BIOZ   STBIT,*+     ;Bit length = 3*(AR0) cycles
          SAR    AR1,BITLEN   ;
          LARK   AR2,9        ;wait for 8 bits + 2 stop bit
          SACL   MODE         ; MODE=1 (MULTIPROCESSOR)
AUTOB2    LAR    AR1, BITLEN  ;
          BANZ   $,*-         ;wait (BITLEN +2) cycles
          LARP   AR2          ;
          BANZ   AUTOB2,*-,AR1;last bit in word?
          B      COMMON       ;execute common download PG
COPRO1    ;-----------------------------------------------
          ; COPROCESSOR (PARALLEL I/O) MODE
          ;-----------------------------------------------
          BIOZ   COPRO        ;BIO low -> COPROCESSOR
          B      GLITCH       ;BIO high -> Made mistake
COPRO     LACK   0            ;
          SACL   MODE         ;init MODE 0=COPROCESSOR
COMMON:   ;-----------------------------------------------
          CALL   READ         ;read status word
          SACL   MEMORY       ;
          BIT    MEMORY,POSRD ;D3 (download) = high?
          BBZ    BLOCK        ;No, then >BLOCK CONFIG
          LAC    MEMORY       ;Store Statusword in
          SACL   STATUS       ;STATUS
          CALL   READ         ;read interrupt mask
          SACL   INTER        ;
          CALL   READ         ;Read Program-Length
          AND    MASKFF       ;mask unused bit
          SACL   LENGTH       ;
          LAC    STATUS,8     ;high-Byte
          ANDK   0700h        ;mask unused bit
          OR     LENGTH       ;High-Byte and Low-Byte
```

```
         SACL   LENGTH       ;into Program-Length
         LRLK   AR7,ADRESS   ;Init. address
         LAR    AR6,LENGTH   ;Init. counter value
         BIT    STATUS,POSST ;D4 (16 bit format)= high?
         BBZ    LOW8L,*,AR7  ;No, then go to LOW8L
         ZAC                 ;
LOW16    BIOZ   LOW16        ;BIO-Input = high?
         RXF                 ;Set Ready-Signal
HIGH16   BIOZ   READ16       ;BIO-Input = low?
         B      HIGH16       ;
READ16   IN     *,PA0        ;Read Program-Data
         SXF                 ;Reset Ready-Signal
         ADD    *+,0,AR6     ;Accumulate Checksum
         BANZ   LOW16,*-,AR7 ;Last Word?
         SACL   CHECK        ;
         CALL   READ         ;read checksum
         CALL   CHKSUM       ;test checksum
         B      BLOCK        ;
LOW8L    CALL   READ         ;Read Program-Data LSB
         AND    MASKFF       ;mask unused bit
         SACL   WORD8L       ;--> Low-Byte
         CALL   READ         ;Read Program-Data MSB
         SACL   WORD8H       ;--> high-Byte
         LAC    CHECK        ;
         ADD    WORD8L       ;Accumulate Checksum
         ADD    WORD8H,8     ;Accumulate Checksum
         SACL   CHECK        ;
         LAC    WORD8H,8     ;Modify Program-Data
         OR     WORD8L       ;--> High-Byte+Low-Byte
         SACL   *+,0,AR6     ;Store Block B0\1\3
         BANZ   LOW8L,*-,AR7 ;Last Word?
CHKRID   CALL   READ         ;read checksum LSB
         AND    MASKFF       ;mask unused bit
         SACL   WORD8L       ;
         CALL   READ         ;read checksum MSB
         SACL   WORD8H       ;
         LAC    WORD8H,8     ;
         OR     WORD8L       ;--> High-Byte+Low-Byte
         CALL   CHKSUM       ; test checksum
*-----------------------------------------------*
* CONFIGURE B0, B1 & B3 AND THEN WAIT FOR      *
* FOR START SIGNAL (BIO=0) TO JUMP TO PROGRAM *
*-----------------------------------------------*
BLOCK    BIT    INTER,BCB2   ;Block-Config-Bit2=1?
         conf   3            ;Set all Prog.-Memory
         bbnz   POINT0       ;
         BIT    INTER,BCB1   ;Block-Config-Bit1=1?
         conf   2            ;Set B0,B1 Prog.-Mem.
         bbnz   POINT0       ;
         CONF   1            ;Set B0 Prog.-Memory
POINT0   LAC    INTER        ;init Interrupts
         SACL   IMR          ;of Interrupt-Word
         CALL   READ         ;dummy read for synchro
NEED2    SSXM                ;
```

```
          B      PROG,*,AR0    ;branch to user prog (B0)
                 ;-----------------------------
READ      LAC    MODE          ;
          BZ     READP         ;MODE ?
READS:                         ;MULTIPROCESSOR->RS232 link
          LARK   AR2,0         ;init. byte value
WSTBIT    BIOZ   STOK,*,AR1    ;wait for start bit falling edge
          B      WSTBIT        ;
          ;-------------------------------------------------;
          ; Note: The following sequence uses a shift and   ;
          ; decriment arangement to scale BITLEN for proper ;
          ; RS232 timing.  In this case the time in the     ;
          ; loop is 1/2 the length of the start bit         ;
          ;-------------------------------------------------;
STOK      lac    BITLEN,6      ;BITLEN is scaled and
half_len  subk   171           ;decremented by 8/3 for
          bgz    half_len      ;BITLEN/2 wait
          ;-----------------------------------------
          LARK   AR3,7         ;number of bits - 1
          LARK   AR0,1         ;bit number 1 value
WTBIT     CALL   BIT           ;wait for a bit
          BANZ   WTBIT,*-,AR1  ;last bit ?
          LARK   AR0,0         ;stop bit value
          CALL   BIT           ;wait for stop bit
          SAR    AR2,MEMORY    ;
          LAC    MEMORY        ;ACC == RS232 byte value
          LARP   AR7           ;
          RET                  ;ACC = read value
BIT       LAR    AR1,BITLEN    ;
          BANZ   $,*-          ;wait for a bit
          BIOZ   ZEROBT,*,AR2  ;test bit value = 0 ?
          MAR    *0+           ;add bit value
ZEROBT    LARP   AR0           ;
          MAR    *0+,AR3       ;dble bit val for next bit
          RET                  ;
          ;-----------------------------------------------
READP:                         ;COPROCESSOR ->par intface
          BIOZ   READP         ;BIO-Input = high?
          RXF                  ;Set Ready-Signal
HIGHST    BIOZ   READP2        ;BIO-Input = low?
          B      HIGHST        ;
READP2    IN     MEMORY,PA0    ;Read value
          SXF                  ;Reset Ready-Signal
          LAC    MEMORY        ;ACC = read value
          RET                  ;
CHKSUM:   ;-----------------------------------------------
          SXF                  ; XF =   1 ->checksum OK
          LARK   AR6,0FFh      ;AR6 = >FF ->checksum OK
          SUB    CHECK         ;
          BZ     CHKOK         ;checksum OK ?
          RXF                  ;XF =    0 ->checksum error
          LARK   AR6,00h       ;AR6 = >00 ->checksum error
CHKOK     SAR    AR6,MEMORY    ;
          OUT    MEMORY,PA0    ;OUTPUT PORT->checksum flag
          RET                  ;
```

```
************************************************************
*                    EPROM BOOTLOAD                        *
************************************************************
Full_Load:  lrlk   AR1, LEPROM      ;
Test_Load1: lark   AR2, 080h        ; Entry = Global DS
            sar    AR2, GREG        ; Load length = AR1
Test_Load2: lrlk   AR7, EPROM–1     ; Entry = Norm DS
            lrlk   AR3, ADRESS      ; load destination
moreEPROM:  adrk   2                ; point to LOW word
            lac    MASKFF           ; only load lower 8 bits
            and    *–               ; get upper 8 bits
            add    *+,8,AR3         ; store value
            sacl   *                ; reloading clears MSB’s
            lac    *+,AR1           ; Mask upper bits
            banz   moreEPROM,*–,AR7 ; Finished load?
            sach   GREG             ; Set normal DS
            sblk   0FF80h           ; Accu = B(ranch)?
            ret                     ;
```

5.2 Program Control

To facilitate the use of the TMS320C2x in general-purpose high-speed processing, a variety of instructions are provided for software stack expansion, subroutine calls, timer operation, single-instruction loops, and external branch control. Descriptions and examples of how to use these features of the TMS320C2x are given in this section.

5.2.1 Subroutines

The TMS320C2x has a 16-bit program counter (PC) and a eight-level hardware stack for PC storage. The CALL and CALA subroutine calls store the current contents of the program counter on the top of the stack. The RET (return from subroutine) instruction then pops the top of the stack to the program counter.

Example 5–6 illustrates the use of a subroutine to determine the square root of a 16-bit number. Processing proceeds in the main routine to the point where the square root of a number should be taken. At this point a CALL is made to the subroutine, transferring control to that section of the program memory for execution and then returning to the calling routine via the RET instruction when execution has completed.

Example 5–6. Subroutines

```
*  AUTOCORRELATION
*
*  THIS ROUTINE PERFORMS A CORRELATION OF TWO VECTORS AND THEN CALLS A SQUARE ROOT
*  SUBROUTINE THAT WILL DETERMINE THE RMS AMPLITUDE OF THE WAVEFORM.
*
AUTOC
      .
      .
      .
      LAC    ENERGY
      CALL   SQRT
      SACL   ENERGY
      .
      .
      .
*
*  SQUARE ROOT
*
*  THIS SUBROUTINE DETERMINES THE SQUARE ROOT OF A NUMBER X THAT IS LOCATED IN THE
*  LOW HALF OF THE ACCUMULATOR WHEN THE ROUTINE IS CALLED. THE FRACTIONAL SQUARE
*  ROOT OF XS TAKEN, WHERE 0 < X < 1 AND WHERE 1 IS REPRESENTED BY 7FFFh. THE
*  RESULT IS RETURNED TO THE CALLING ROUTINE IN THE ACCUMULATOR.
*
ST0    .set  60h               ; SAVED STATUS REGISTER ST0 ADDRESS
ST1    .set  61h               ; SAVED STATUS REGISTER ST1 ADDRESS
NUMBER .set  62h               ; NUMBER X WHOSE SQUARE ROOT IS TAKEN
TEMPR  .set  63h               ; INTERMEDIATE ROOTS
```

```
GUESS  .set  64h                ; SQUARE ROOT OF X*

*
       .text
SQRT   SST    ST0               ; SAVE STATUS REGISTER ST0.
       SST1   ST1               ; SAVE STATUS REGISTER ST1.
       LDPK   0                 ; LOAD DATA PAGE POINTER = 0.
       SSXM                     ; SET SIGN-EXTENSION MODE.
       SPM 1                    ; LEFT-SHIFT PR OUTPUT TO ACCUMULATOR.
       SACL   NUMBER            ; SAVE X.
       LARP   AR1               ; INITIALIZE VARIABLES FOR SQUARE ROOT.
       LARK   AR1,11            ; 12 ITERATIONS
       LALK   800h              ; ASSUME X IS LESS THAN 200h.
       SACL   GUESS             ; SET INITIAL GUESS TO 800h.
       SACL   TEMPR             ; SET FIRST INTERMEDIATE ROOT TO 800h.
       SACH   ROOT              ; SET SQUARE ROOT VALUE TO 0.
       LAC    NUMBER            ; LOAD X INTO THE ACCUMULATOR.
       SBLK   200h              ; TEST IF X IS LESS THAN 200h.
       BLZ    SQRTLP            ; IF YES, TAKE THE ROOT;
       LAC    GUESS,3           ; IF NO, THEN REINITIALIZE.
       SACL   GUESS             ; SET INITIAL GUESS TO 4000h.
       SACL   TEMPR             ; SET FIRST INTERMEDIATE ROOT TO 4000h.
       LARK   AR1,14            ; 15 ITERATIONS
*
*      SQUARE ROOT LOOP
*
SQRTLP SQRA   TEMPR             ; SQUARE TEMPORARY (INTERMEDIATE) ROOT.
       ZALH   NUMBER            ; CHECK IF RESULT IS LESS THAN X.
       SPAC
       BLZ    NEXTLP            ; IF IT'S NOT, SKIP ROOT UPDATE.
       ZALH   TEMPR             ; IF IT IS, SET ROOT EQUAL TEMPR.
       SACH   ROOT
NEXTLP LAC    GUESS,15          ; SCALE DOWN GUESS BY 2 TO CONVERGE.
       SACH   GUESS
       ADDH   ROOT              ; ADD CURRENT ROOT ESTIMATE.
       SACH   TEMPR             ; UPDATE TEMPORARY ROOT VALUE.
       BANZ   SQRTLP            ; REPEAT SPECIFIED NO. OF ITERATIONS.
       LAC    ROOT              ; LOAD THE ROOT OF X.
       LST1   ST1               ; RESTORE STATUS REGISTER ST1.
       LST    ST0               ; RESTORE STATUS REGISTER ST0.
       RET
```

The hardware stack is allocated for use in interrupts, subroutine calls, pipelined instructions, and debugging. The TMS320C2x disables all interrupts when it takes an interrupt trap. If interrupts are enabled more than one instruction before the return of the interrupt service routine, the routine can also be interrupted, thus using another level of the hardware stack. This condition should be considered when managing the use of the stack. When nesting subroutine calls, each call uses a level of the stack. The number of levels used by the interrupt must be remembered as well as the depth of the nesting of subroutines. One level of the stack is reserved for debugging, to be used for breakpoint/single-step operations. If debugging is not used, this extra level is available for internal use.

5.2.2 Software Stack

Provisions have been made on the TMS320C2x for extending the hardware stack into data memory. This is useful for deep subroutine nesting or stack overflow protection.

Use the PUSH and POP instructions to access the hardware stack via the accumulator. Two additional instructions, PSHD and POPD, are included in the instruction set so that the stack may be directly stored to and recovered from data memory.

A software stack can be implemented by using the POPD instruction at the beginning of each subroutine in order to save the PC in data memory. Then before returning from a subroutine, a PSHD is used to put the proper value back onto the top of the stack.

When the stack has seven values stored on it and two or more values are to be put on the stack before any other values are popped off, a subroutine that expands the stack is needed, such as shown in Example 5–7. In this example, the main program stores the stack starting location in memory in AR2 and indicates to the subroutine whether to push data from memory onto the stack or pop data from the stack to memory. If a zero is loaded into the accumulator before calling the subroutine, the subroutine pushes data from memory to the stack. If a one is loaded into the accumulator, the subroutine pops data from the stack to memory.

Because the CALL instruction uses the stack to save the program counter, the subroutine pops this value into the accumulator and utilizes the BACC (branch to address specified by accumulator) instruction to return to the main program. This prevents the program counter from being stored into a memory location. The subroutine in Example 5–7 uses the BANZ (branch on auxiliary register not zero) instruction to control all of its loops.

Example 5–7. Software Stack Expansion

```
*  THIS ROUTINE EXPANDS THE STACK WHILE LETTING THE MAIN PROGRAM DETERMINE WHERE
*  TO STORE THE STACK CONTENTS OR FROM WHERE TO RECOVER THEM.
*
STACK  LARP  2                ; USE AR2.
       BNZ   PO               ; IF POPD IS NEEDED, GO TO PO.
       POP                    ; ELSE, SAVE PROGRAM COUNTER.
       RPTK  6                ; LOAD REPEAT COUNTER.
       PSHD  *+               ; PUT MEMORY IN STACK.
       BACC                   ; RETURN TO MAIN PROGRAM.
PO     POP                    ; SAVE PROGRAM COUNTER.
       MAR   *–               ; ALIGN STACK POINTER.
       RPTK  6                ; LOAD REPEAT COUNTER.
       POPD  *–               ; PUT STACK IN MEMORY.
       MAR   *+               ; REALIGN STACK POINTER.
       BACC                   ; RETURN TO MAIN PROGRAM.
```

5.2.3 Timer Operation

The TMS320C2x 16-bit on-chip timer and its associated interrupt perform various functions at regular time intervals. On the TMS320C25, the timer is a down counter that is continuously clocked by CLKOUT1 and counts (PRD + 1) cycles of CLKOUT1. By programming the period (PRD) register from 1 to 65,535 (0FFFFh), a timer interrupt (TINT) can be generated every 2 to 65,536 cycles. (A period register value of zero is not allowed.)

Two memory-mapped registers operate the timer. The timer (TIM) register, data memory location 2, holds the current count of the timer. At every CLKOUT1 cycle, the TIM register is decremented by one. The PRD register, data memory location 3, holds the starting count for the timer. When the TIM register decrements to zero, a timer interrupt (TINT) is generated. In the following cycle, the contents of the PRD register are loaded into the TIM register. In this way, a TINT is generated every (PRD + 1) cycles of CLKOUT1 on the TMS320C25.

You can read from or write to the timer and period registers on any cycle. You can monitor the count by reading the TIM register and write a new counter period to the PRD register without disturbing the current timer count. The timer will then start the new period after the current count is complete. If both the PRD and TIM registers are loaded with a new period, the timer begins decrementing the new period without generating an interrupt. Thus, you have complete control of the current and next periods of the timer.

For the TMS320C25, the TIM register is set to the maximum value on reset (0FFFFh), and the PRD register is also initialized by reset to 0FFFFh. The TIM register begins decrementing only after $\overline{RS}$ is deasserted. If the timer is not used, TINT should be masked. The PRD register can then be used as a general-purpose data memory location. If you use TINT, you should program the PRD and TIM registers before unmasking the TINT.

Example 5–8 shows the assembly code that implements the timer to divide down the CLKOUT1 signal. To generate a 9600-Hz clock signal, load the PRD register with 520. In the timer interrupt service routine, the XF line is toggled. The XF output is used also as an input for $\overline{BIO}$ in this example. The output of XF will provide a 50-percent duty cycle clock signal as long as the main routine or other interrupt routines do not disable interrupts. Interrupts may be disabled by direct or implied use of DINT or by executing instructions in the repeat mode. The value for the PRD register is calculated as follows:

TMS320C25:

CLKOUT1/(PRD + 1) = 2 × frequency of signal
10 MHz/(520 + 1) = 2 × 9600 Hz (= 9597 Hz for divided signal)

Example 5–8. Clock Divider Using Timer (TMS320C25)

```
* SETUP FOR INTERRUPT SERVICE ROUTINE.
*
      LALK   520
      SACL   DMA3              ; LOAD THE PERIOD REGISTER.
      LACK   8
      OR     DMA4
      SACL   DMA4              ; ENABLE THE TIMER INTERRUPT.
      EINT                     ; ENABLE INTERRUPTS.
         .
         .
         .
*       I/O SERVICE ROUTINE.
*
TIME  BIOZ   SET1              ; CHECK THE CURRENT XF STATE.
      RXF                      ; XF WAS HIGH; SET IT LOW.
      EINT                     ; ENABLE INTERRUPTS.
      RET                      ; RETURN TO INTERRUPTED CODE.
SET1  SXF                      ; XF WAS LOW; SET IT HIGH.
      EINT                     ; ENABLE INTERRUPTS.
      RET                      ; RETURN TO INTERRUPTED CODE.
```

5.2.4 Single-Instruction Loops

When programming time-critical high-computational tasks, it is often necessary to repeat the same operation many times. For these tasks, the TMS320C2x has repeat instructions that allow the execution of the next single instruction N+1 times. N is defined by an eight-bit repeat counter (RPTC), which is loaded by the RPT or RPTK instructions. The instruction immediately following is then executed, and the RPTC is decremented until it reaches zero.

When you use the repeat feature, the instruction being repeated is fetched only once. As a result, many multicycle instructions become single-cycle when repeated. This is especially useful for I/O instructions, such as TBLR/TBLW, IN/OUT, or BLKD/BLKP.

Since the instruction is fetched and internally latched, the program bus can be used to fetch or write a second operand in parallel to operations using the data bus. With the instruction latched for repeated execution, the program counter can be loaded with a data address and incremented on succeeding executions to fetch data in successive memory locations. As an example, the MAC instruction fetches the multiplicand from program memory via the program bus. Simultaneously with the program bus fetch, the second multiplicand is fetched from data memory via the data bus. In addition to these data fetches, preparation is made for accesses in the following cycles by incrementing the program counter and by indexing the auxiliary register. TBLR is another example of an instruction that benefits from simultaneous transfers of data on both the program and data buses. In this case, data values from a table in program memory may be read and transferred to data memory. When repeated, the program overhead of reading the instruction from program memory must be executed only once, thus allowing the rest of the executions to operate in a single cycle.

Programs, such as those implementing digital filters, require loops that execute in a minimum amount of time. Example 5–9 shows the use of the RPT or RPTK instructions.

Example 5–9. Instruction Repeating

```
*  THIS ROUTINE USES THE RPT INSTRUCTION TO SET UP THE LOOP COUNTER IN ONE CYCLE.
*  THE FOLLOWING EQUATION IS IMPLEMENTED IN THIS ROUTINE:
*  10
*  _____
*  \   X(I) x Y(I)
*  /
*  _____
*  I = 1
*
*  THIS ROUTINE ASSUMES THAT THE X VALUES ARE LOCATED IN ON-CHIP RAM BLOCK B0, AND
*  THE Y VALUES IN BLOCK B1. WHEN REPLACING RPT NUM WITH RPTK 9, THE PROGRAM WILL
*  EXECUTE THE SAME WAY.
*
SERIES LARP  AR4
       CNFP                    ; CONFIG BLOCK B0 AS PROGRAM MEMORY.
       LACK  9                 ; SET COUNTER TO 9.
       SACL  NUM               ; (NUM) = 9.
       LRLK  AR4,300h          ; POINT AT BEGINNING OF DATA.
       MPYK  0h                ; CLEAR P REGISTER.
       ZAC                     ; CLEAR ACCUMULATOR.
       RPT   NUM               ; EXECUTE NEXT INSTRUCTION 10 TIMES.
       MAC   0FF00h,*+         ; MULTIPLY-ACCUMULATE; INCREMENT AR4.
       APAC
       RET                     ; RETURN TO MAIN PROGRAM.
```

5.2.5 Computed GOTOs

Processing may be executed in a time- and process-dependent or selected way. Following a specific time or data processing path may then result in selecting one of several processing options.

You can program a simple computed GOTO in the TMS320C2x by using the CALA instruction. This instruction uses the contents of the accumulator as the direct address of the call. Thus, the call address can be computed in the ALU, as shown in Example 5–10.

Example 5–10. Computed GOTO

```
*  TASK CONTROLLER
*
*  THIS MAIN TASK ROUTINE CONTROLS THE ORDER OF EXECUTION AND SCHEDULING OF TASKS.
*  WHEN AN INTERRUPT OCCURS, THE INTERRUPT SERVICE ROUTINE IS EXECUTED TO PROCESS
*  THE INPUT AND OUTPUT DATA SAMPLES. AFTER THE INTERRUPT SERVICE ROUTINE HAS
*  COMPLETED,THE PROCESSOR BEGINS EXECUTION WITH THE INSTRUCTION FOLLOWING THE
*  IDLE INSTRUCTION. THIS ROUTINE SELECTS THE TASK APPROPRIATE FOR THE CURRENT
*  SAMPLE CYCLE, CALLS THE TASK AS A SUBROUTINE, AND BRANCHES BACK TO THE IDLE TO
*  WAIT FOR THE NEXT SAMPLE INTERRUPT  WHEN THE SCHEDULED TASK HAS COMPLETED
*  EXECUTION.
*
WAIT   IDLE                    ; WAIT FOR SAMPLE INTERRUPT.
       LAC    SAMPLE           ; FETCH SAMPLE COUNT VALUE.
       SUB    ONE              ; DECREMENT THE SAMPLE COUNT.
       BGEZ   OVRSAM           ; TEST FOR END OF BAUD INTERVAL.
       LACK   15               ; INIT COUNT FOR NEW BAUD INTERVAL.
OVRSAM SACL   SAMPLE           ; SAVE NEW COUNT VALUE.
       ADLK   TSKSEQ           ; ADD TASK TABLE BASE ADDRESS.
       TBLR   TEMP             ; READ SUBROUTINE TASK ADDRESS.
       LAC    TEMP             ; LOAD ACCUMULATOR FOR TASK CALL.
       CALA                    ; EXECUTE APPROPRIATE TASK.
       B      WAIT
*
TSKSEQ
      .word  DUMMY             ; 15 – UNUSED CYCLE
      .word  DUMMY             ; 14 – UNUSED CYCLE
      .word  DUMMY             ; 13 – UNUSED CYCLE
      .word  DUMMY             ; 12 – UNUSED CYCLE
      .word  BDCLK2            ; 11 – COMPUTE ENERGY E(11)
      .word  DUMMY             ; 10 – UNUSED CYCLE
      .word  OUT               ;  9 – COMMUNICATE WITH U-CONTROLLER
      .word  DECODE            ;  8 – DECODE/GET SCRAMBLED DIBIT
      .word  DEMODB            ;  7 – DEMODULATE IN MIDDLE OF BAUD
      .word  DUMMY             ;  6 – UNUSED CYCLE
      .word  AGCUPT            ;  5 – UPDATE AGC EVERY 3RD BAUD
      .word  DUMMY             ;  4 – UNUSED CYCLE
      .word  BDCLK1            ;  3 – COMPUTE ENERGY E(3)
      .word  DUMMY             ;  2 – UNUSED CYCLE
      .word  DUMMY             ;  1 – UNUSED CYCLE
      .word  DUMMY             ;  0 – UNUSED CYCLE
```

5.3 Interrupt Service Routine

Interrupts on the TMS320C2x are prioritized and vectored. When an interrupt occurs, the corresponding flag is set in the interrupt flag register (IFR). If the corresponding bit in the interrupt mask register (IMR) is set and interrupts are enabled (INTM=0), then interrupt processing begins.

When the interrupt vector is loaded into the program counter, interrupts are disabled (INTM=1) and a branch is made to the appropriate routine via the branch instruction stored at the associated vector location. Since all interrupts are disabled, interrupt processing will proceed without further interruption unless the interrupt service routine (ISR) re-enables interrupts.

Unless the interrupt service routines are simple I/O handlers, the processing in each ISR generally must assure that the processor context is preserved during execution. The context must be saved before the routine executes and must be restored when the routine is finished. A common routine or routines individualized for each interrupt may be used to secure the context of the processor during interrupt processing. Context switching is also useful for subroutine calls, especially when extensive use is made of the stack or auxiliary registers. Code examples of context switching and an interrupt service routine are provided in this section.

5.3.1 Context Switching

Context switching, commonly required when processing a subroutine call or interrupt, may be quite extensive or simple, depending on the system requirements. On the TMS320C2x, the program counter is stored automatically on the hardware stack. If there is any important information in the other TMS320C2x registers, such as the status or auxiliary registers, these must be saved by software command. A stack in data memory, identified by an auxiliary register, is useful for storing the machine state when processing interrupts.

Example 5–11 and Example 5–12 show how to save and restore the state of the TMS320C25. Auxiliary register 7 (AR7) in both examples is the stack pointer. As the stack grows, it expands into lower memory addresses. The status registers (ST0 and ST1), accumulator (ACCH and ACCL), product register (PR), temporary register (TR), all eight levels of the hardware stack, and the auxiliary registers (AR0 through AR6) are saved.

The routines in Example 5–11 and Example 5–12 are protected against interrupts, allowing context switches to be nested. This is accomplished by the use of the MAR*– and MAR*+ instructions at the beginning of the context save and context restore routines, respectively. Note that the last instruction of the context save decrements AR7, while the context restore is completed with an additional increment of AR7. This prevents the loss of data if a context save or restore routine is interrupted.

Example 5–11. Context Save (TMS320C25)

```
       .title 'CONTEXT SAVE'
       .def SAVE
*
* CONTEXT SAVE ON SUBROUTINE CALL OR INTERRUPT.
*
* ASSUME AR7 IS THE STACK POINTER AND AR7 = 128.
*
SAVE  LARP   AR7               ;(ARP) → ARB, 7 → ARP,          AR7 = 128
      MAR    *–                ;                               AR7 = 127
*
* SAVE THE STATUS REGISTERS.
      SST1   *–                ; ST1 → (127),                  AR7 = 126
      SST    *–                ; ST0 → (126),                  AR7 = 125
*
* SAVE THE ACCUMULATOR.
      SACH   *–                ; ACCH → (125),                 AR7 = 124
      SACL   *–                ; ACCL → (124),                 AR7 = 123
*
* SAVE THE P REGISTER.
      SPM    0                 ; NO SHIFT ON PR OUTPUT
      SPH    *–                ; PRH → (123),                  AR7 = 122
      SPL    *–                ; PRL → (122),                  AR7 = 121
*
* SAVE THE T REGISTER.
      MPYK   1                 ; PR = TR
      SPL    *–                ; TR → (121),                   AR7 = 120
*
* SAVE ALL EIGHT LEVELS OF THE HARDWARE STACK.
      RPTK   7
      POPD   *–                ; TOS (8) → (120),              AR7 = 119
*                              ; STACK(7) → (119),             AR7 = 118
*                              ; STACK(6) → (118),             AR7 = 117
*                              ; STACK(5) → (117),             AR7 = 116
*                              ; STACK(4) → (116),             AR7 = 115
*                              ; STACK(3) → (115),             AR7 = 114
*                              ; STACK(2) → (114),             AR7 = 113
*                              ; BOS (1) → (113),              AR7 = 112
*
* SAVE AUXILIARY REGISTERS AR0 THROUGH AR6.
      SAR    AR0,*–            ; AR0 → (112),                  AR7 = 111
      SAR    AR1,*–            ; AR1 → (111),                  AR7 = 110
      SAR    AR2,*–            ; AR2 → (110),                  AR7 = 109
      SAR    AR3,*–            ; AR3 → (109),                  AR7 = 108
      SAR    AR4,*–            ; AR4 → (108),                  AR7 = 107
      SAR    AR5,*–            ; AR5 → (107),                  AR7 = 106
      SAR    AR6,*–            ; AR6 → (106),                  AR7 = 105
*
* SAVE IS COMPLETE.
*
```

Example 5–12. Context Restore (TMS320C25)

```
       .title 'CONTEXT RESTORE'
       .def RESTOR
*
* CONTEXT RESTORE AT THE END OF A SUBROUTINE OR INTERRUPT.
*
* ASSUME AR7 IS THE STACK POINTER AND AR7 = 105.
*
RESTOR   LARP AR7              ; (ARP), → ARB, 7 → ARP,          AR7 = 105
         MAR  *+               ;                                 AR7 = 106
*
* RESTORE AUXILIARY REGISTERS AR0 THROUGH AR6.
         LAR  AR6,*+           ; (106) → AR6,                    AR7 = 107
         LAR  AR5,*+           ; (107) → AR5,                    AR7 = 108
         LAR  AR4,*+           ; (108) → AR4,                    AR7 = 109
         LAR  AR3,*+           ; (109) → AR3,                    AR7 = 110
         LAR  AR2,*+           ; (110) → AR2,                    AR7 = 111
         LAR  AR1,*+           ; (111) → AR1,                    AR7 = 112
         LAR  AR0,*+           ; (112) → AR0,                    AR7 = 113
*
* RESTORE ALL EIGHT LEVELS OF THE HARDWARE STACK.
         RPTK 7
         PSHD *+               ; (113) → BOS (1),                AR7 = 114
                               ; (114) → STACK(2),               AR7 = 115
                               ; (115) →  STACK(3),              AR7 = 116
*                              ; (116) → STACK(4),               AR7 = 117
*                              ; (117) → STACK(5),               AR7 = 118
*                              ; (118) → STACK(6),               AR7 = 119
*                              ; (119) → STACK(7),               AR7 = 120
*                              ; (120) → TOS (8),                AR7 = 121
*
* THE RETURN PC IS NOW ON TOP OF THE STACK FOR THE RET INSTRUCTION. THE LOWER 16
* BITS OF THE P REGISTER MUST BE LOADED VIA THE T REGISTER AND THE STACK POINTER
* BE POINTING AT THE VALUE TO BE LOADED IN THE T REGISTER.
*
* RESTORE THE LOW P REGISTER.
         MAR  *+               ; SKIP T REGISTER,                AR7 = 122
         LT   *–               ; (122) → TR,                     AR7 = 121
         MPYK 1                ; (TR) → PRL
*
* RESTORE THE T REGISTER.
         LT   *+               ; (121) → TR,                     AR7 = 122
         MAR  *+               ; SKIP P REGISTER LOW,            AR7 = 123
*
* RESTORE THE HIGH P REGISTER.
         LPH  *+               ; (123) → PRH,                    AR7 = 124
*
* RESTORE THE ACCUMULATOR.
         ZALS *+               ; (124) → ACCL,                   AR7 = 125
         ADDH *+               ; (125) → ACCH,                   AR7 = 126
*
* RESTORE THE STATUS REGISTERS.
         LST  *+               ; (126) → ST0,                    AR7 = 127
         LST1 *+               ; (127) → ST1,                    AR7 = 128
*
* RESTORE IS COMPLETE.
         EINT                  ; ENABLE INTERRUPTS.
         RET                   ; RETURN TO INTERRUPTS OR
                               ; CALLING ROUTINE.
```

5.3.2 Interrupt Priority

Interrupts on the TMS320C2x are prioritized in hardware. This allows interrupts that occur simultaneously to be serviced in a prioritized order. Sometimes priority may be determined by frequency or rate of occurrence. An infrequent, but lengthy, ISR might need to be interrupted by a more frequently occurring interrupt. In the routine of Example 5–13, the ISR for $\overline{\text{INT}}$1 temporarily modifies the IMR to permit interrupt processing when an interrupt on $\overline{\text{INT}}$0 (but no other interrupt) occurs. When the routine has finished processing, the IMR is restored to its original state.

Example 5–13. Interrupt Service Routine

```
      .title 'INTERRUPT SERVICE ROUTINE'
      .def   ISR1
      .ref   IMR
*
*  INTERRUPT PROCESSING FOR EXTERNAL INTERRUPT INT1–.
*
*  THIS ROUTINE MAY BE INTERRUPTED BY AN INTERRUPT FROM THE EXTERNAL INTERRUPT
*  INT0–, BUT NO OTHER.
*
*
ISR1  LARP   AR7               ; 7 → ARP
      MAR    *–                ;                              AR7 = AR7 – 1
      SST1   *–                ; ST1 → *AR7,                  AR7 = AR7 – 1
      SST    *–                ; ST0 → *AR7,                  AR7 = AR7 – 1
      SACH   *–                ; ACCH → *AR7,                 AR7 = AR7 – 1
      SACL   *–                ; ACCL → *AR7,                 AR7 = AR7 – 1
      LDPK   0                 ; DP = 0
      PSHD   IMR               ; IMR → TOS
      LACK   0001h             ; MASK FOR INT0–
      AND    IMR               ; MASK CURRENT IMR CONTENTS.
      SACL   IMR               ; ACC → IMR
      EINT                     ; ENABLE INTERRUPTS.
*
* MAIN PROCESSING SECTION FOR ISR1.
      .
      .
      .
*
      DINT                     ; DISABLE INTERRUPTS.
      LDPK   0                 ; DP = 0
      POPD   IMR               ; TOS → IMR
      LARP   AR7               ; AR7 → ARP
      MAR    *+                ;                              AR7 = AR7 + 1
      ZALS   *+                ; *AR7 → ACCL,                 AR7 = AR7 + 1
      ADDH   *+                ; *AR7 → ACCH,                 AR7 = AR7 + 1
      LST    *+                ; *AR7 → ST0,                  AR7 = AR7 + 1
      LST1   *+                ; *AR7 → ST1,                  AR7 = AR7 + 1
      EINT                     ; ENABLE INTERRUPTS.
      RET
```

5.4 Memory Management

The structure of the TMS320C2x memory map is programmable and can vary for each application. Instructions are provided for moving blocks of data or program memory, configuring a block of on-chip data RAM as program memory, and defining part of external data memory as global. Explanations and examples of moving, configuring, and manipulating memory are provided in this section.

5.4.1 Block Moves

Since the TMS320C2x directly addresses a large amount of memory, blocks of data or program code can be stored off-chip in slow memories and then loaded on-chip for faster execution. Data can also be moved from on-chip to off-chip for storage or for multiprocessor data transfers.

The BLKD and BLKP instructions facilitate memory-to-memory block moves on the TMS320C2x. The BLKD instruction moves a block within data memory as shown in Example 5–14. Data may also be transferred between data memory and program memory by means of the TBLR and TBLW instructions. The instructions IN and OUT are used to transfer data between the data memory and the I/O space.

Example 5–14. Moving External Data to Internal Data Memory With BLKD

```
*  THIS ROUTINE USES THE BLKD INSTRUCTION TO MOVE A BLOCK OF EXTERNAL DATA MEMORY
*  (DATA PAGES 8 AND 9) TO INTERNAL BLOCK B1 (DATA PAGES 6 AND 7).
*
MOVED LARP   AR2
      LRLK   AR2,300h           ; DESTINATION IS BLOCK B1 IN RAM.
      RPTK   255                ; REPEAT NEXT INSTRUCTION 256 TIMES.
      BLKD   400h,*+            ; MOVE EXTERNAL BLOCK TO BLOCK B1.
      RET                       ; RETURN TO MAIN PROGRAM.
```

For systems that have external program memory but no external data memory, BLKP can be used to move program memory blocks into data memory. Example 5–15 demonstrates how to use the BLKP instruction.

Example 5–15. Moving Program Memory to Data Memory with BLKP

```
* THIS ROUTINE USES THE BLKP INSTRUCTION TO MOVE DATA VALUES FROM PROGRAM MEMORY
* INTO DATA MEMORY. SPECIFICALLY, THE VALUES IN LOCATIONS 2, 3, 4, AND 5 IN
* PROGRAM MEMORY ARE MOVED TO LOCATIONS 512, 513, 514, AND 515 IN DATA MEMORY.
*
MOVEP LARP   AR2               ; SET REFERENCE FOR INDIRECT ADDRESSING.
      LRLK   AR2,512           ; LOAD BEGINNING OF BLOCK B0 IN AR2.
      RPTK   3                 ; SET UP LOOP.
      BLKP   2h,*+             ; PUT DATA INTO DATA RAM.
      RET                      ; RETURN TO MAIN PROGRAM.
```

The TBLR instruction is another method for transferring data from program memory into data memory. When the TBLR instruction is used, a calculated, rather than predetermined, location of a block of data in program memory may be specified for transfer. A routine using this approach is shown in Example 5–16.

Example 5–16. Moving Program Memory to Data Memory With TBLR

```
* THIS ROUTINE USES THE TBLR INSTRUCTION TO MOVE DATA VALUES FROM PROGRAM MEMORY
* INTO DATA MEMORY. BY USING THIS ROUTINE, THE PROGRAM MEMORY LOCATION IN THE
* ACCUMULATOR FROM WHICH DATA IS TO BE MOVED TO A SPECIFIC DATA MEMORY LOCATION
* CAN BE SPECIFIED. ASSUME THAT THE ACCUMULATOR CONTAINS THE ADDRESS IN PROGRAM
* MEMORY FROM WHICH TO TRANSFER THE DATA.
*
TABLER   LARP     AR3
         LRLK     AR3,380       ; DESTINATION ADDRESS = PAGE 7.
         RPTK     127           ; TRANSFER 128 VALUES.
         TBLR     *+            ; MOVE DATA INTO DATA RAM.
         RET                    ; RETURN TO CALLING PROGRAM.
```

In cases where systems require that temporary storage be allocated in the program memory, TBLW can be used to transfer data from internal data memory to external program memory. The code in Example 5–17 demonstrates how to do this.

Example 5–17. Moving Internal Data Memory to Program Memory With TBLW

```
* THIS ROUTINE USES THE TBLW INSTRUCTION TO MOVE DATA VALUES FROM INTERNAL DATA
* MEMORY TO EXTERNAL PROGRAM MEMORY. THE CALLING ROUTINE MUST SPECIFY THE
* DESTINATION PROGRAM MEMORY ADDRESS IN THE ACCUMULATOR. ASSUME THAT THE
* ACCUMULATOR CONTAINS THE ADDRESS IN PROGRAM MEMORY INTO WHICH THE DATA IS
* TRANSFERRED.
*
*
*
*
*
*
TABLEW   LARP     AR4
         LRLK     AR4,380       ; SOURCE ADDRESS = PAGE 7.
         RPTK     127           ; TRANSFER 128 VALUES.
         TBLW     *+            ; MOVE DATA TO EXTERNAL PROGRAM RAM.
         RET                    ; RETURN TO CALLING PROGRAM.
```

The IN and OUT instructions are used to transfer data between the data memory and the I/O space, as shown in Example 5–18 and Example 5–19.

Example 5–18. Moving Data From I/O Space Into Data Memory With IN

```
*  THIS ROUTINE USES THE IN INSTRUCTION TO MOVE DATA VALUES FROM THE I/O SPACE
*  INTO DATA MEMORY. DATA ACCESSED FROM I/O PORT 15 IS TRANSFERRED TO SUCCESSIVE
*  MEMORY LOCATIONS ON DATA PAGE 5.
*
INPUT LARP   AR2
      LRLK   AR2,2C0h          ; DESTINATION ADDRESS = PAGE 5.
      RPTK   63                ; TRANSFER 64 VALUES.
      IN     *+,PA15           ; MOVE DATA INTO DATA RAM.
      RET                      ; RETURN TO CALLING PROGRAM.
```

Example 5–19. Moving Data From Data Memory to I/O Space With OUT

```
* THIS ROUTINE USES THE OUT INSTRUCTION TO MOVE DATA VALUES FROM THE DATA MEMORY
* TO THE I/O SPACE.  DATA IS TRANSFERRED TO I/O PORT 8 FROM SUCCESSIVE MEMORY
* LOCATIONS ON DATA PAGE 4.
*
OUTPUT   LARP     AR4
         LRLK     AR4,200h      ; SOURCE ADDRESS = PAGE 4.
         RPTK     63            ; TRANSFER 64 VALUES.
         OUT      *+,PA8        ; MOVE DATA FROM DATA RAM.
         RET                    ; RETURN TO CALLING PROGRAM.
```

5.4.2 Configuring On-Chip RAM

TMS320C2x

The large amount of external memory and the configurability of on-chip RAM simplify the downloading of data or program memory into the TMS320C2x. Also, since data in the RAM is preserved when redefining on-chip RAM, block B0 can be configured dynamically as either data or program memory. Figure 5–9 illustrates the changes in on-chip RAM when switching configurations.

On-chip memory is configured by a reset or by the CNFD and CNFP instructions. Block B0 is configured as data memory by executing CNFD or reset. A CNFP instruction configures block B0 as program memory.

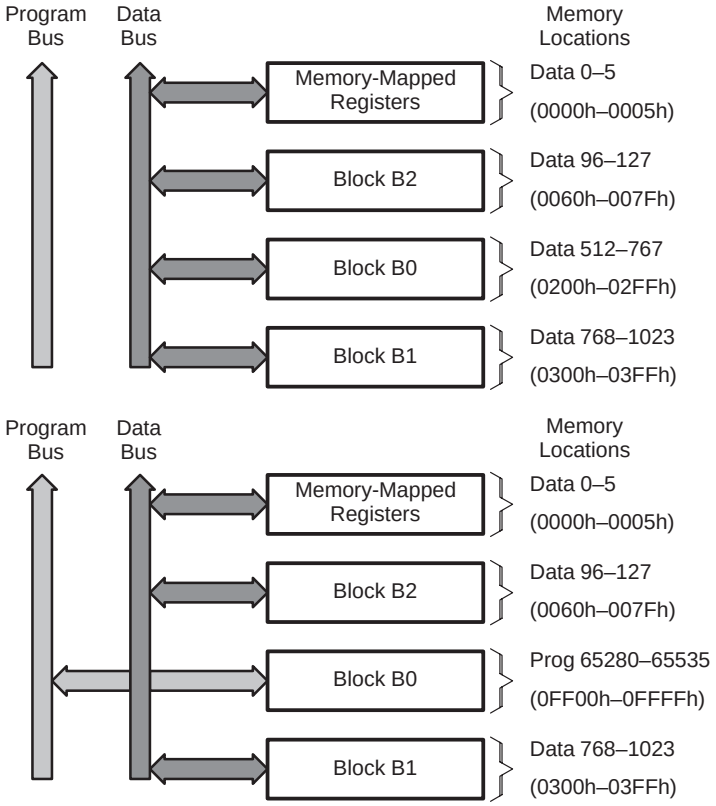
TMS320C26

The reconfigurable memory space of the TMS320C26 is different in both the number of configurable blocks and the size of the blocks. For the TMS320C2x, only 256 words in Block B0 are reconfigurable using the CNFD and CNFP instructions. The TMS320C26 has three reconfigurable blocks—B0, B1 and B3—each 512 words in length.

Four possible configurations for the three blocks of the TMS320C26 are set with the immediate instruction CONF. The configuration instructions CNFD and CNFP are not defined for the TMS320C26, and CONF is not defined for the TMS320C2x.

Because the start and stop addresses of internal memory are not the same, applications using the reconfigurable memory of the TMS320C2x will need to be redefined. The memory maps and block descriptions are given in subsection 3.4.3 and in Appendix B.

Figure 5–9. On-Chip RAM Configurations



Configuring block B0 as program memory is useful for implementing adaptive filters or similar applications at full speed with only on-chip memories. Example 5–20 illustrates the use of the configuration modes to utilize block B0 as data and program memory while executing from its on-chip program ROM. Note that a more definitive example of the use of the TMS320C25 for adaptive filtering is provided in subsection 5.7.3.

Example 5–20. Configuring and Using On-Chip RAM

```
   .title 'ADAPTIVE FILTER'
   .def   ADPFIR
   .def   X, Y
*
* THIS 128-TAP ADAPTIVE FIR FILTER USES ON-CHIP MEMORY BLOCK B0 FOR COEFFICIENTS
* AND BLOCK B1 FOR DATA SAMPLES. THE NEWEST INPUT SHOULD BE IN MEMORY LOCATION X
* WHEN CALLED. THE OUTPUT WILL BE IN MEMORY LOCATION Y WHEN RETURNED.
*
COEFFP .set   0FF00h            ; B0 PROGRAM MEMORY ADDRESS
COEFFD .set   0200h             ; B0 DATA MEMORY ADDRESS
ONE    .set   7Ah               ; CONSTANT ONE (DP = 6)
BETA   .set   7Bh               ; ADAPTATION CONSTANT (DP = 6)
ERR    .set   7Ch               ; SIGNAL ERROR (DP = 6)
ERRF   .set   7Dh               ; ERROR FUNCTION (DP = 6)
Y      .set   7Eh               ; FILTER OUTPUT (DP = 6)
X      .set   7Fh               ; NEWEST DATA SAMPLE (DP = 6)
FRSTAP .set   0380h             ; NEXT NEWEST DATA SAMPLE
LASTAP .set   03FFh             ; OLDEST DATA SAMPLE
*
* FINITE IMPULSE RESPONSE (FIR) FILTER.
*
ADPFIR CNFP                     ; CONFIGURE B0 AS PROGRAM:
       MPYK   0                 ; CLEAR THE P REGISTER.
       LAC    ONE,14            ; LOAD OUTPUT ROUNDING BIT.
       LARP   AR3
       LRLK   AR3,LASTAP        ; POINT TO THE OLDEST SAMPLE.
FIR    RPTK   127
       MACD   COEFFP, *-        ; 128-TAP FIR FILTER.
       CNFD                     ; CONFIGURE B0 AS DATA:
       APAC
       SACH   Y,1               ; STORE THE FILTER OUTPUT.
       NEG
       ADD    X,15              ; ADD THE NEWEST INPUT.
       SACH   ERR,1             ; ERR(N) = X(N) – Y(N)
*
* LMS ADAPTATION OF FILTER COEFFICIENTS.
*
       LT     ERR
       MPY    BETA              ; 128-TAP FIR FILTER.
       PAC                      ; ERRF(N) = BETA * ERR(N)
       ADD    ONE,14            ; ROUND THE RESULT.
       SACH   ERRF,1
       LARP   AR3
       LARK   AR1,127           ; 128 COEFFICIENTS TO UPDATE.
       LRLK   AR2,COEFFD        ; POINT TO THE COEFFICIENTS.
       LRLK   AR3,LASTAP        ; POINT TO THE DATA SAMPLES.
       DMOV   X                 ; INCLUDE NEWEST SAMPLE.
       LT     ERRF
       MPY    *-,AR2            ; P = 2*BETA*ERR(N)*X(N – K)
*
ADAPT  ZALH   *,AR3             ; LOAD ACCH WITH AK(N).
       ADD    ONE,15            ; LOAD ROUNDING BIT.
       APAC                     ; AK(N + 1) = AK(N) + P
*      MPY    *-,AR2            ; P = 2*BETA*ERR(N)*X(N–K)
       SACH   *+,0,AR1          ; STORE AK(N + 1).
       BANZ   ADAPT,*-,AR2      ; END OF LOOP TEST.
       RET                      ; RETURN TO CALLING ROUTINE.
```

5.4.3 Using On-Chip RAM for Program Execution

To use on-chip memory (block B0) for program execution, you must first load this memory with executable code from external memories while it is configured as data memory. On-chip execution is initiated by using the CNFP instruction to reconfigure block B0 as program memory and performing a branch or call to an on-chip RAM address. By configuring block B0 as program memory and executing from this internal memory, you can achieve full-speed execution in systems using slower external memory. Example 5–21 illustrates how to write a program to be loaded into and executed from on-chip memory.

One group of instructions, the branch/call instructions, are impacted by the location of execution. Normally, by using labels, the assembler properly determines the location to which a branch is taken. Because the code is relocated prior to execution from on-chip memory, it is necessary to alter the address determined by the assembler for branch instructions. This alteration is necessary so that the branch address that is determined can be consistent with the address space used during execution. In Example 5–21, this is accomplished by use of the .asect directive. The .asect directive simply indicates that the named section is to be assembled as if it were at the specified address. The addresses defined within this named section are absolute with respect to the specified address. The section may, then, be placed in any area of program memory by the linker and relocated at runtime to its fixed location for execution as is shown in this example. The code in Example 5–22 for the TMS320C26 is equivalent to the code in Example 5–21 written for the rest of the TMS320C2x.

Example 5–21. Program Execution from On-Chip Memory

```
   .title "ON-CHIP RAM PROGRAM EXECUTION EXAMPLE"
   .width 96
   .option X
   .text
RESET B    INIT
*
* BRANCHES FOR EXTERNAL OR INTERNAL INTERRUPTS FOLLOW HERE AT THE DESIGNATED
* LOCATIONS AS REQUIRED.
*
*
       .space (32–($–RESET))*16
*
* A BRANCH INSTRUCTION AT PROGRAM MEMORY LOCATION 0 DIRECTS PROCESSOR EXECUTION
* HERE.
*
*
* INITIALIZE THE PROCESSOR.
*
INIT  ROVM                      ; DISABLE OVERFLOW MODE.
      SSXM                      ; SET SIGN EXTENSION.
      LDPK   0                  ; POINT DP REGISTER TO DATA MEMORY PAGE 0.
      SPM    0                  ; NO SHIFT ON PRODUCT REGISTER OUTPUT.
      LARP   AR4                ; USE AUXILIARY REGISTER 4 (SET ARP = 4).
      LARK   AR4,PRD            ; POINT AR4 TO PERIOD REGISTER.
      LALK   0FFFFh             ; SET ACCUMULATOR TO 0000FFFFh.
      SACL   *+                 ; LOAD PERIOD REGISTER WITH MAXIMUM VALUE.
      SACL   *+                 ; ENABLE ALL INTERRUPTS VIA IMR.
      ZAC                       ; CLEAR ACCUMULATOR.
      SACH   *                  ; CLEAR GREG TO MAKE ALL MEMORY LOCAL.
*
*  LOAD TIME-CRITICAL CODE FROM EXTERNAL SLOW MEMORY TO INTERNAL RAM
*
      LARP   AR1                ; USE AUXILIARY REGISTER 1 (SET ARP = 1).
      LRLK   AR1,PROGR          ; POINT AR1 TO RECONFIGURABLE BLOCK B0.
      RPTK   PROGL–1            ; LOAD REPEAT COUNTER WITH BLOCK LENGTH.
      BLKP   P1_START,*+        ; MOVE CODE FROM PROG MEMORY TO ON-CHIP RAM
*
* INITIALIZE PARAMETERS FOR EXECUTION.
*
      LDPK   6                  ; POINT DP REGISTER TO DATA MEMORY PAGE 6.
      LACK   1                  ; SET ACCUMULATOR TO 0001h.
      SACL   ONE                ; STORE VALUE OF 1.
      LRLK   AR1,COEFF          ; POINT AR1 TO INTERNAL MEMORY ADDRESS.
      RPTK   COEFL–1            ; LOAD REPEAT COUNTER WITH BLOCK LENGTH.
      BLKP   C1_START,*+        ; MOVE DATA FROM PROG MEMORY TO ON-CHIP RAM.
      CNFP                      ; CONFIGURE BLOCK B0 AS PROGRAM MEMORY.
      LALK   LPTS               ; LOAD ACC WITH PROG ADDR IN INTERNAL RAM.
      BACC                      ; BRANCH TO ON-CHIP EXECUTION ADDRESS.
*
*  SIGNAL PROCESSING CODE TO BE EXECUTED FROM ON-CHIP RAM.
*
      .asect "on-chip",0FF00h
PROG  .label P1_START
LPTS  BIOZ   GET                ; WAIT FOR INPUT SIGNAL.
      B      LPTS               ; BRANCH IF NO SIGNAL.
```

```
GET   OUT    FILOUT,PA2         ; OUTPUT LAST FILTER OUTPUT.
      IN     FILIN,PA2          ; INPUT NEW SIGNAL SAMPLE.
      LRLK   AR1,SIGNAL         ; POINT AR1 TO SIGNAL DATA TO PROCESS.
      ZAC                       ; CLEAR THE ACCUMULATOR.
      MPYK   0                  ; CLEAR THE P REGISTER.
      RPTK   15                 ; REPEAT MACD INSTRUCTION FOR 16 TAPS.
      MACD   COEF,*-            ; MULTIPLY, ACCUMULATE, SAMPLE DELAY.
      APAC                      ; ACCUMULATE THE LAST PRODUCT.
      SACH   FILOUT,1           ; SAVE THE RESULT.
      B      PTS                ; LOOP TO WAIT FOR NEXT SAMPLE.
PROGE .label P1_END
PROGL .equ   PROGE-PROG          ; PROGRAM CODE LENGTH.
*
* COEFFICIENT DATA TO BE LOADED INTO ON-CHIP RAM.
*
COEF  .label C1_START
      .word  385,-1196,1839,-2009
      .word  1390,407,-4403,19958
      .word  19958,-4403,407,1390
      .word  -2009,1839,-1196,385
COEFE .label C1_END
COEFL .equ   COEFE-COEF          ; COEFFICIENT DATA LENGTH.
* DATA PAGE 0 (BLOCK B2) - DATA MEMORY LABELS.
*
      .bss   DRR,1              ; SERIAL PORT DATA RECEIVE REGISTER.
      .bss   DXR,1              ; SERIAL PORT DATA TRANSMIT
      .bss   TIM,1              ; TIMER REGISTER.
      .bss   PRD,1              ; PERIOD REGISTER.
      .bss   IMR,1              ; INTERRUPT MASK REGISTER.
      .bss   GREG,1             ; GLOBAL MEMORY ALLOCATION REGISTER.
*
      .bss   RSVRD0,05Ah
*
      .bss   B2,020h
*
      .bss   RSVRD1,0180h
*
* DATA PAGE 4 (BLOCK B0) - DATA MEMORY LABELS.
*
B0    .bss   PROGR,PROGL         ; LOCATIONS FOR INTERNAL PROGRAM CODE.
      .bss   COEFF,COEFL         ; LOCATIONS FOR COEFFICIENT MEMORY.
      .bss   FREE0,0100h-(PROGL+COEFL)
*
* DATA PAGE 6 (BLOCK B1) - DATA MEMORY LABELS.
*

B1    .bss   ONE,1               ; RESERVED FOR DATA VALUE OF 1.
      .bss   FILOUT,1            ; FILTER OUTPUT SIGNAL VALUE.
      .bss   FILIN,1             ; FILTER INPUT SIGNAL VALUE.
      .bss   SIG,13
      .bss   SIGNAL,1            ; LAST SIGNAL DELAY VALUE.
      .end
```

Example 5–22. Program Execution From On-Chip Memory (TMS320C26)

```
       .file  onchip26
       .title ON-CHIP RAM PROGRAM EXECUTION EXAMPLE FOR THE TMS320C26
       .width 96
       .option   X
PGMBO  .set   0FA00h            ;
BLKSIZ .set   00200h            ; BLOCKSIZE OF TMS320C26
       .text
RESET  B      INIT,*,AR1          ;  ARP = AR1
*
* BRANCHES FOR EXTERNAL OR INTERNAL INTERRUPTS FOLLOW HERE AT THE DESIGNATED
* LOCATIONS AS REQUIRED.
*
   .space (32-($-RESET))*16
*
* A BRANCH INSTRUCTION AT PROGRAM MEMORY LOCATION 0 DIRECTS PROCESSOR EXECUTION
* HERE.
*
*
INIT  ROVM                      ; DISABLE OVERFLOW MODE
      LDPK    0                 ; POINT DP REGISTER TO DATA MEMORY PAGE 0
*
* LOAD TIME-CRITICAL CODE FROM EXTERNAL SOW MEMORY TO INTERNAL RAM
*
      LRLK   AR1,PROGR          ; POINT AR1 INTO RECONFIGURABLE BLOCK B0
      RPTK   PROGL-1            ; LOAD REPEAT COUNTER WITH BLOCK LENGTH
      BLKP   P1_START,*+        ; MOVE CODE FROM PROGRAM MEMORY TO ON-CHIP RAM
*
* INITIALIZE PARAMETERS FOR EXECUTION.
*
      LDPK   8                  ; POINT DP REGISTER TO DATA MEMORY PAGE 8
      LACK   1                  ; SET ACCUMULATOR TO 0001h
      SACL   ONE                ; STORE VALUE OF 1
      LRLK   AR1,COEFF          ; POINT AR1 TO INTERNAL MEMORY ADDRESS
      RPTK   COEFL-1            ; LOAD REPEAT COUNTER WITH BLOCK LENGTH
      CONF   1                  ; BLOCK B0 = PROGRAM MEMORY / B1, B3 = DATA MEMORY
      B      LPTS               ; BRANCH TO ON-CHIP EXECUTION ADDRESS
*
* SIGNAL PROCESSING CODE TO BE EXECUTED FROM ON-CHIP RAM.
*
      .asect ”ONCHIP”, PGMBO
PROG  .LABEL P1_START
LPTS  BIOZ   GET                ; WAIT FOR SIGNAL = LOW
      B      LPTS               ; BRANCH IF SIGNAL = HIGH
GET   OUT    FILOUT,PA2         ; OUTPUT LAST FILTER OUTPUT
      IN     FILIN,PA2          ; INPUT NEW SIGNAL SAMPLE
      LRLK   AR1,SIGNAL         ; POINT AR1 TO SIGNAL DATA TO PROCESS
      ZAC                       ; CLEAR THE ACCUMULATOR
      MPYK   0                  ; CLEAR THE P REGISITER
      RPTK   15                 ; REPEAT MACD INSTRUCTION FOR 16 TAPS
      MACD   COEF,*–            ; MULTIPLY/ACCUMULATE, SAMPLE DELAY
      APAC                      ; Accumulate the last product
      SACH   FILOUT,1           ; Save the result
      B      LPTS               ; Loop to wait for next sample
PROGE .label P1_END
PROGL .equ   PROGE-PROG         ; Program code lenth
*
* Coefficient data to be loaded into on-chip RAM
*
```

```
COEF  .label C1_START
      .word  385,-1196,1839,-2009
      .word  1390,407,-4403,19958
      .word  19958,-4403,407,1390
      .word  -2009,1839,-1196,385
COEFE .label C1_END
COEFL .equ   COEFE-COEF         ; Coefficient data length
*
* Data page 0 (Block B2) – Data memory labels.
*
      .bss   DRR,1              ; Serial port data receive register
      .bss   DXR,1              ; Serial port data transmit register
      .bss   TIM,1              ; Timer register
      .bss   PRD,1              ; Period register
      .bss   IMR,1              ; Interrupt mask register
      .bss   GREG,1             ; Global memory allocation register
*
      .bss   RSVRD0,05Ah
*
      .bss   B2,020h
*
      .bss   RSVRD1,0180h
*
* Data page 4 (Block B0) – Data memory labels.
*
B0    .bss   PROGR,PROGL        ; Location for internal program code
      .bss   COEFF,COEFL        ; Location for coefficent memory
      .bss   FREE0,0100h – (PROGL + COEFL)
*
* Data page 6 (block B1) – data memory labels
B1    .bss   ONE,1              ; Reserved for data value of 1
      .bss   FILOUT,1           ; Filter output signal value
      .bss   FILIN,1            ; Filter input signal value
      .bss   SIG,13
      .bss   SIGNAL,1           ; Last signal delay value
      .end
```

5.5 Fundamental Logical and Arithmetic Operations

Although the TMS320C2x instruction set is oriented toward digital signal processing, the same fundamental operations of a general-purpose processor are included. This section explains basic operations of the TMS320C2x central arithmetic logic unit (CALU), particularly accumulator operations, the status register effect on data processing, and bit manipulation.

The TMS320C2x provides a complete set of logical operations, including AND, OR, XOR, and CMPL (complement) instructions. This enables the device to perform any logical function. These instructions can convert sign magnitude to 2s complement or the reverse.

You can store the contents of the accumulator in data memory with the SACH and SACL instructions or in the stack with the PUSH instruction. You can load the accumulator from data memory with the ZALH and ZALS instructions, which zero the accumulator before loading the data value. The ZAC instruction zeros the accumulator. POP can be used to restore the accumulator contents from the stack.

The accumulator is also affected by the ABS and NEG instructions. ABS replaces the contents of the accumulator with the absolute value of its contents. NEG generates the arithmetic complement of the accumulator in complement form.

5.5.1 Status Register Effect on Data Processing

Three data processing options allow the ALU to automatically suppress sign extension, manage overflow, or scale product accumulations. These options are enabled or disabled through bits in the status registers and function in parallel with normal execution of the instructions. They cause no additional machine cycles and therefore no performance overhead.

The sign-extension mode option is used to determine whether or not the shifted data values fetched for ALU operations should be sign-extended. The SXM status bit controls this operation. The SSXM instruction sets this bit to 1 for enabling sign extension, and the RSXM instruction sets it to 0 for suppressing sign extension. This operation affects all the instructions that include a shift of the incoming data value, that is, ADD, ADDT, ADLK, LAC, LACT, LALK, SBLK, SFR, SUB, and SUBT.

The overflow mode option minimizes the effects of an arithmetic overflow by forcing the accumulator to saturate at the largest positive value (or in the case of underflow, the largest negative value). The OVM status bit controls this operation. The overflow mode is enabled by setting the OVM bit to a 1 with the SOVM instruction, and reset with the ROVM instruction. This feature affects all arithmetic operations in the ALU.

The product register shift mode option forces all products to be shifted before they are accumulated. The products can be left-shifted one bit to delete the extra sign bit when two 16-bit signed numbers are multiplied. The products can be left-shifted four bits to delete the extra sign bits in multiplying a 16-bit data value by a 13-bit constant. The product shifter can also be used to shift all products six bits to the right to allow up to 128 product accumulations without the threat of an arithmetic overflow, thereby avoiding the overhead of overflow management. The shifter can be disabled to cause no shift in the product when working with integer or 32-bit precision operations. This also maintains compatibility with TMS320C1x code. These operations are controlled by the value contained in the PM bits of status register ST1. The SPM instruction sets the PM bits. This feature affects all the instructions that use the product of the multiplier, that is, APAC, LTA, LTD, LTP, LTS, MAC, MACD, MPYA, MPYS, PAC, SPAC, SPH, SPL, SQRA, and SQRS.

5.5.2 Bit Manipulation

The BIT instruction tests any of the 16 bits of the addressed data word. The specified bit is copied into the TC of the status register. The bit tested is specified by a bit code in the opcode of the instruction. Both the BBZ (branch on TC bit = 0) and BBNZ (branch on TC bit = 1) instructions check the bit and allow branching to a service routine.

Bit testing is useful in control applications where a number of states or conditions may be latched externally and read into the TMS320C2x via an IN instruction. At this point, individual bits can be tested and branches taken for appropriate processing.

Because the BIT instruction requires the bit code to be specified with the instruction, it cannot be placed in a loop to test several different bits of a data word or bits determined by prior processing for efficient use. The TMS320C2x also has a BITT instruction in which the bit code is specified in the T register. Because the T register can easily be modified, BITT may be used to test all bits of a data word if placed within a loop or to test a bit location determined by past processing.

Example 5–23. Using BIT and BBZ

```
* THIS ROUTINE USES THE BIT INSTRUCTION TO TEST THE CONDITION OF AN EXTERNAL MUX.
* BIT 4 DETERMINES THE UTILITY OF THE REMAINING DATA. IF ZERO, A COUNTER IS
* INCREMENTED. IF ONE, ADDITIONAL PROCESSING OCCURS AND THE COUNTER IS CLEARED.
* THE ROUTINE IS INVOKED WHENEVER A TIMER INTERRUPT OCCURS.
*
TIME  SST    ST0               ; SAVE STATUS REGISTER ST0.
      LDPK   0
      LARP   AR3
      IN     DAT,PA8           ; READ IN VALUE.
      BIT    DAT,0Bh           ; TEST BIT 4.
      BBZ    INCR              ; BRANCH AND INCREMENT IF POSITIVE.
      .
      .
      .
      LARK   AR3,0             ; CLEAR THE COUNTER.
      LST    ST0               ; RELOAD THE STATUS REGISTER.
      EINT                     ; ENABLE INTERRUPTS.
      RET                      ; RETURN TO INTERRUPTED ROUTINE.
*
INCR  MAR    *+                ; INCREMENT THE COUNTER.
      LST    ST0               ; RELOAD THE STATUS REGISTER.
      EINT                     ; ENABLE INTERRUPTS.
      RET                      ; RETURN TO INTERRUPTED ROUTINE.
```

Example 5–24. Using BITT and BBNZ

```
* THIS ROUTINE USES THE BITT INSTRUCTION TO TEST THE CONDITION OF AN EXTERNAL
* MUX. A BIT IN THE MUX IS SIGNIFICANT ONLY WHEN PRIOR PROCESSING HAS DESIGNATED
* THE BIT TO BE ACTIVE. INDIVIDUAL PROCESSING WILL TAKE PLACE BASED UPON THE
* STATE OF THE TESTED BIT. THE BITS ARE TESTED EACH TIME A TIMER INTERRUPT
* OCCURS.
*
TIME   SST        ST0           ; SAVE STATUS REGISTER ST0.
       LDPK  0
       LARP  AR3
       LAR   AR3,BCNT           ; LOAD COUNT OF ACTIVE BITS.
       LRLK  AR4,BTBL           ; LOAD THE BIT TABLE ADDRESS.
       IN    DAT,PA8            ; READ IN VALUE.
       B     LTEST,*-,4
TMLOOP LT    *+,3               ; LOAD BIT CODE.
       BITT  DAT                ; TEST SPECIFIED BIT.
       BBNZ  LTEST              ; BRANCH IF BIT IS ONE.
       .
       .
       .
LTEST  BANZ  TMLOOP,*-,4
       LST   ST0                ; RELOAD THE STATUS REGISTER.
       EINT                     ; ENABLE INTERRUPTS.
       RET                      ; RETURN TO INTERRUPTED ROUTINE.
```

5.6 Advanced Arithmetic Operations

The TMS320C2x provides instructions, such as MACD, SQRA, SUBC, and NORM, that facilitate efficient execution of arithmetic-intensive DSP algorithms. Explanations and examples of how to use these instructions with overflow management and for data move, multiplication-accumulation, division, floating-point arithmetic, indexed addressing, and extended-precision arithmetic are included in this section.

5.6.1 Overflow Management

The TMS320C2x has four features that can be used to handle overflow management: the branch on overflow conditions, accumulator saturation (overflow mode), product register right shift, and accumulator right shift. These features provide several options for overflow protection within an algorithm.

A program can branch to an error handler routine on an overflow of the accumulator by using the BV (branch on overflow) instruction or bypass an error handler by using the BNV (branch if no overflow) instruction. These instructions can be performed after any ALU operation that may cause an accumulator overflow.

The overflow mode is a useful feature for DSP applications. This mode simulates the saturation effect characteristic of analog systems. When enabled, any overflow in the accumulator results in the accumulator contents being replaced with the largest positive value (7FFFFFFFh) if the overflowed number is positive, or the largest negative value (80000000h) if negative. The overflow mode is controlled by the OVM bit of status register ST0 and can be changed by the SOVM (set overflow mode), ROVM (reset overflow mode), or LST (load status register) instructions. Overflows can be detected in software by testing the OV (overflow) bit in status register ST0. When a branch is used to test the overflow bit, OV is automatically reset. Note that the OV bit does not function as a carry bit. It is set only when the absolute value of a number is too large to be represented in the accumulator, and it is not reset except by specific instructions.

Another method of overflow management, which applies to multiply-accumulate operations, is the use of the right shifter of the product register. The right shifter, which operates with no cycle overhead, allows up to 128 accumulations without the possibility of an overflow. The least significant six bits of the product are lost, and the MSBs are filled with sign bits. This feature is initiated by setting the PM bits of status register ST1 to 11 with the SPM or LST1 instructions.

The TMS320C2x also has a right shift of the accumulator (using the SFR instruction) to scale down the accumulator when it nears overflow.

5.6.2 Scaling

Scaling the data coming into the accumulator or already in the accumulator is useful in signal processing algorithms. This is frequently necessary in adaptation or other algorithms that must compute and apply correction factors or normalize intermediate results. Scaling and normalizing are implemented on the TMS320C2x via right and left shifts in the accumulator and shifts of data on the incoming path to the accumulator.

Right and left shifts of the accumulator can be performed using the SFL and SFR instructions. SFL performs a logical left shift. SFR performs logical or arithmetic right shifts depending on the state of the SXM bit in the status register. A one in the SXM bit, corresponding to sign-extension enabled, causes an arithmetic shift to be performed.

In addition to the shift instructions, data can be left-shifted 0 to 15 bits when the accumulator is loaded by using a LAC instruction, and left-shifted 0 to 7 bits on the TMS320C2x when storing from the accumulator by using SACH or SACL instructions. These shifts can be used for loading numbers into the high 16 bits of the accumulator and renormalizing the result of a multiply. The incoming left shift of 0 to 15 bits can be supplied in the instruction itself or can be taken from the lowest four bits of the T register. Left shifts of data fetched from data memory are available for loading the accumulator (LAC/LACT), adding to the accumulator (ADD/ADDT), and subtracting from the accumulator (SUB/SUBT). The contents of the P register may also be shifted prior to accumulation.

5.6.3 Shifting Data

You can perform a logical right or left shift on the TMS320C25 in parallel with another instruction without disturbing the accumulator, multiplier or any other part of the ALU. Two important features of the ARAU — besides its capacity to increment, decriment, and index — make this possible.

First, to double the value of a number, you need only to add it to itself. Simply stated, the ARAU can have the current ARP=0 such that a *0+ modification will add AR0 to itself. The code would look this way:

```
lrlk   AR0,Value  ; load a value into AR0
larp   AR0        ; point the current ARP to AR0
mar    *0+        ; add AR0 to itself (logical left shift!)
```

Second, for bit-reversed carry addition in the ARAU, the logic of the ARAU propogates the carries from any half adder to the *right*, instead of left as in a normal addition. In otherwords, bit-reversed carry addition works as if you were looking at the inputs and outputs with a mirror; it reverses the order. Note that this also causes the LSBs to swap places with the MSBs. Two examples are given. Example 5–25 shows AR0 bit reverse added to itself (ARP=0). Example 5–26 shows what is normally used in FFT bit reversals and other DSP algorithms (ARP != 0), with a “mirror” line drawn for reference.

Example 5–25. Bit-Reversed Carry Addition

```
   LRLK   AR0,07191h   ;
   LARP   AR0          ;
   MAR    *BR0+        ; Note carries propogate right

        C  C  C          C  C       1
   0  1  1  1  0  0  0  1  1  0  0  1  0  0  0  1  <-- AR0
+  0  1  1  1  0  0  0  1  1  0  0  1  0  0  0  1  <-- AR0
   0  0  1  1  1  0  0  0  1  1  0  0  1  0  0  0  <-- New AR0
      C> C> C>         C> C>      C>         C>    (last carry
                                                   is lost)
```

Example 5–26. FFT Bit Reversals

```
   LRLK   AR1,0800h
   LRLK   AR0,0080h
   LARP   AR1
   RPTK   7
   MAR    *BR0+
```

```
                                  Mirror
                                   Line
                LSB           MSB  |   MSB           LSB
                0000100000000000   |   0000000000010000
          *BR0+ 0000000010000000   | + 0000000100000000
                -------------------|  -------------------
AR1 Bits        0000100000000000   |   0000000000010000
                0000100010000000   |   0000000100010000
                0000100001000000   |   0000001000010000
                0000100011000000   |   0000001100010000
                0000100000100000   |   0000010000010000
                0000100010100000   |   0000010100010000
                0000100001100000   |   0000011000010000
                0000100011100000   |   0000011100010000
                0000100000010000   |   0000100000010000
     Bit Reversed carry --->>      |   <<--- Normal carry
```

Bit-reversed carry addition is effective as a logical shifter that does not use the accumulator in any way. Here are some other applications:

- Suppose you want to do a decimation in frequency FFT. In this case, the DFT block size decreases by one-half for every stage of the FFT. When finished, the DFT block size will be two, and the address will be offset by one. If you use a BANZ Not_done,*BR0+, excess code is eliminated in a tightly looped and reasonably efficient FFT. Also, the value of AR0 can be used at the same time to access a bit-reversed twiddle table lookup. The advantage here is that the same lookup table will work for any size FFT smaller than the overall size of the table permits.

- In another application, AR0 can be loaded with a single bit. This bit is then shifted during each pass through the main loop and used as a test bit. This test is a successive approximation approach to calculating the square root of a 32-bit integer. Example 5–27 shows what the code will look like. Compare this to the same algorithm in subsection 5.2.1.

Example 5–27. Using the AR0 Test Bit to Calculate the Square Root of a Long Integer

```
*************************************************************
* LNG_SQRT.ASM  Calculates the 16 bit sqrt of a long int  *
*                                                           *
* long lng_sqrt(long);    /* C prototype */                 *
*                                                           *
*   s    |-----------|    This routine uses a succesive   *
*   t    |    AR0    |    approximation technique that    *
*   a    |-----------|    holds both the test bit and     *
*   c    |    AR2    |    the guess in ARx registers      *
*   k    |-----------|                                    *
* entry> |   guess   |    mem config   |pi/di|            *
*        |-----------|    -------------|-----|            *
*        | input hi  |    cycles (pos) | 243 |            *
*        |-----------|         (0/neg) |   7 |            *
*        | input lo  |                                    *
*        |-----------|                                    *
*************************************************************
        .global _lng_sqrt
_lng_sqrt:
        blez  ret_0           ;
        adrk  2               ;                  >AR0
        sar   AR0,*–          ;store AR0         >AR2
        sar   AR2,*–          ;store AR2         >AR3
        lrlk  AR0,08000h      ;initial test bit
        lrlk  AR2,08000h      ;initial guess 0
;-----------------------------------------------;
; This section performs successive aproximation  ;
;-----------------------------------------------;
more:   sar   AR2,*           ;store guess
        lt    *               ;square guess (unsigned)
        mpyu  *–              ;
        pac                   ;
        subh  *–              ;ACCU = guess – input
        subs  *+              ;
        mar   *+,AR0          ;
        bgz   too_hi,*BR0+,AR2 ;AR0>>1;  guess^2 > input?
too_low mar   *0+,AR0         ;add test bit if guess too low
        banz  more,*,AR1      ;more test bits?
        b     done            ;
too_hi: mar   *0–,AR0         ;sub test bit if guess too
high
        banz  more,*,AR1      ;more test bits
        larp  AR2             ;Always +1 LSB error
        mar   *–,AR1          ;subtract LSB
done:   sar   AR2,*           ;store final guess (result)
        zals  *+              ;load result in ACCU
        lar   AR2,*+          ;restore AR0 & AR2
        lar   AR0,*           ;
        sbrk  2               ;restore AR1
        ret                   ;
ret_0:  zac                   ;if input <=0
        ret                   ;then return 0
        .end
```

5.6.4 Moving Data

Many DSP applications must perform convolution operations or other operations similar in form. These operations require data to be shifted or delayed. The DMOV, LTD, and MACD instructions can perform the needed data moves for convolution.

The data move function allows a word to be copied from the currently addressed data memory location in on-chip RAM to the next higher location while the data from the addressed location is being operated upon (that is, by the CALU). The data move and the CALU operation are performed in the same cycle. In addition, an ARAU operation may also be performed in the same cycle when using the indirect addressing mode. The data move function is useful in implementing algorithms, such as convolutions and digital filtering, where data is being passed through a time window. It models the z^{-1} delay operation encountered in those applications. The data move function is continuous across the boundary of the on-chip data memory blocks B0, B1, and B2. However, the data move function cannot be used if off-chip memory is referenced.

In Example 5–28, the following equation is implemented:

$$Y(n) = \sum_{k=0}^{2} H(k)X(n - k)$$

where the H values stay the same, and the X values are shifted each time the microprocessor performs one of the following series of multiplications (similar to operations performed in FIR filters):

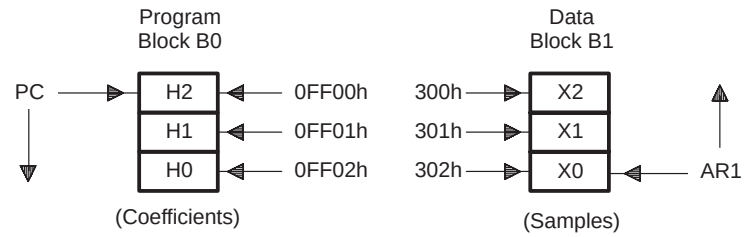
First Series: $Y(2) = (H0)(X2) + (H1)(X1) + (H2)(X0)$

Second Series: $Y(3) = (H0)(X3) + (H1)(X2) + (H2)(X1)$

Third Series: $Y(4) = (H0)(X4) + (H1)(X3) + (H2)(X2)$

The MACD instruction, which combines accumulate and multiply operations with a data move, is tailored to the type of calculation shown in the summation equation above. In order to use MACD, the H values have been stored in block B0 and configured as program RAM; the X values have been read into block B1 of data RAM as shown in Figure 5–10.

Figure 5–10. MACD Operation



Also, in Example 5–28, the summation in the above equation is performed in the reverse order, that is, from K = 2 to 0, because of the operation of the data move function. This results in the oldest X value being used and discarded first.

If the MACD instruction is replaced with the following two instructions, then the MAC instruction can be utilized with the same results.

```
MAC *
DMOV *–
```

In cases where many more than three MACD instructions are required, the RPT or RPTK instructions may be used with MACD, yielding the same computational results but using less assembly code.

Example 5–28. Using MACD for Moving Data

```
* THIS ROUTINE IMPLEMENTS A SINGLE PASS OF A THIRD-ORDER FIR FILTER. IT IS
* ASSUMED THAT THE H AND X VALUES HAVE ALREADY BEEN LOADED INTO THEIR RESPECTIVE
* MEMORY LOCATIONS, THAT THE ACCUMULATOR AND P REGISTER ARE BOTH RESET TO ZERO,
* AND THAT AR1 IS POINTING AT X0. NOTE THAT THE MACD INSTRUCTION MAY BE USED IN
* THE REPEAT MODE, BUT IT IS NOT IMPLEMENTED HERE.
*
*
FIR   CNFP                      ; CONFIGURE BLOCK B0 AS PROGRAM MEMORY.
      LARP   1                  ; AR1 SHOULD POINT AT THE X VALUES.
      MAC    0FF00h,*–          ; P = (X0)(H2)
      MACD   0FF01h,*–          ; ACC = (X0)(H2)
      MACD   0FF02h,*           ; ACC = (X0)(H2) + (X1)(H1)
      APAC                      ; ACC = (X0)(H2) + (X1)(H1) + (X2)(H0)
      CNFD                      ; CONFIGURE BLOCK B0 AS DATA MEMORY.
      RET                       ; RETURN TO MAIN PROGRAM.
```

5.6.5 Multiplication

The TMS320C2x hardware multiplier normally performs 2s-complement 16-bit by 16-bit multiplies and produces a 32-bit result in one processor cycle. A single TMS320C2x instruction, MPYU, can be used to multiply two 16-bit unsigned numbers. To multiply two operands, one operand must be loaded into the T register (TR). The second operand is moved by the multiply instruction to the multiplier, which then produces the product in the P register (PR). Before another multiply can be performed, the contents of the PR must be moved to the accumulator. A single-multiply program is shown in Example 5–29. Pipelining multiplies and PR moves makes it possible to perfom most multiply operations in a single cycle.

A common operation in DSP algorithms is the summation of products. The MAC instruction, normally performed in multiple cycles, adds the contents of the PR to the accumulator and then simultaneously reads two values and multiplies them. When you use the MAC instruction, a data memory value is multiplied by a program memory value. One of the operands can come from block B1 or B2 in on-chip data memory while the other operand may come from block B0. Block B0 must be configured as program memory when it supplies the second operand. Pipelining of the MAC instruction with a repeat instruction results in an execution time for each succeeding multiply-and-accumulate operation of only one cycle.

Example 5–29. Multiply

```
*  THIS ROUTINE MULTIPLIES TWO VALUES IN DATA MEMORY LOCATIONS 200h AND 201h WITH
*  THE RESULT STORED IN 202h AND 203h.
*
MUL   LRLK   AR1,200h          ; POINT AT BLOCK B0.
      LARP   1
      LT     *+                ; GET FIRST VALUE AT 200h.
      MPY    *+                ; MULTIPLY BY VALUE AT 201h.
      PAC                      ; PUT RESULT IN ACCUMULATOR.
      SACL   *+                ; STORE LOW WORD AT 202h.
      SACH   *                 ; STORE HIGH WORD AT 203h.
      RET                      ; RETURN TO MAIN PROGRAM.
```

The pipelining of the MAC and MACD instructions incurs a certain amount of overhead in execution. In those cases where speed is more critical than program memory, it may be beneficial to use LTA or LTD and MPY instructions rather than MAC or MACD. Example 5–30 and Example 5–31 show an implementation of multiply-accumulates using the MAC instruction. Example 5–31 shows an implementation of multiply-accumulates using the LTA-MPY instruction pair. Figure 5–11 and Figure 5–12 provide graphically the information necessary to determine the efficiency of use for each of the techniques.

Example 5–30. Multiply-Accumulate Using the MAC Instruction (TMS320C25)

```
*                    CLOCK          TOTAL CLOCK       PROGRAM      TOTAL PROGRAM
*                   CYCLES            CYCLES          MEMORY          MEMORY
*
LARP   AR1           ; 1                                1
LRLK   AR1,300h      ; 2                                2
CNFP                 ; 1                                1
ZAC                  ; 1                                1
MPYK   0             ; 1                                1
RPTK   N–1           ; 1                                1
MAC    0FF00h,*+     ; 3 + N                            2
APAC                 ; 1              11 + N            1               10
```

Example 5–31. Multiply-Accumulate Using the LTA-MPY Instruction Pair

```
*                    CLOCK          TOTAL CLOCK       PROGRAM      TOTAL PROGRAM
*                   CYCLES            CYCLES          MEMORY          MEMORY
*

ZAC                  ; 1                                1
LT     D1            ; 1                                1
MPY    C1            ; 1                                1
LTA    D2            ; 1                                1
MPY    C2            ; 1                                1
 .
 .                   ;                2N                                2N
 .                   ;
LTA    DN            ; 1                                1
MPY    CN            ; 1                                1
APAC                 ; 1              2+2N              1               2+2N
```

Figure 5–11. Execution Time vs. Number of Multiply-Accumulates (TMS320C25)

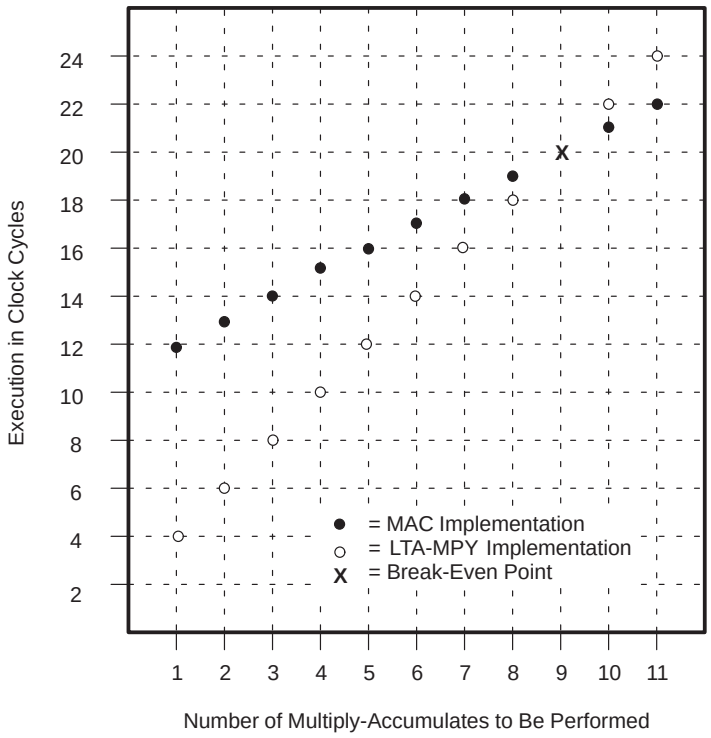
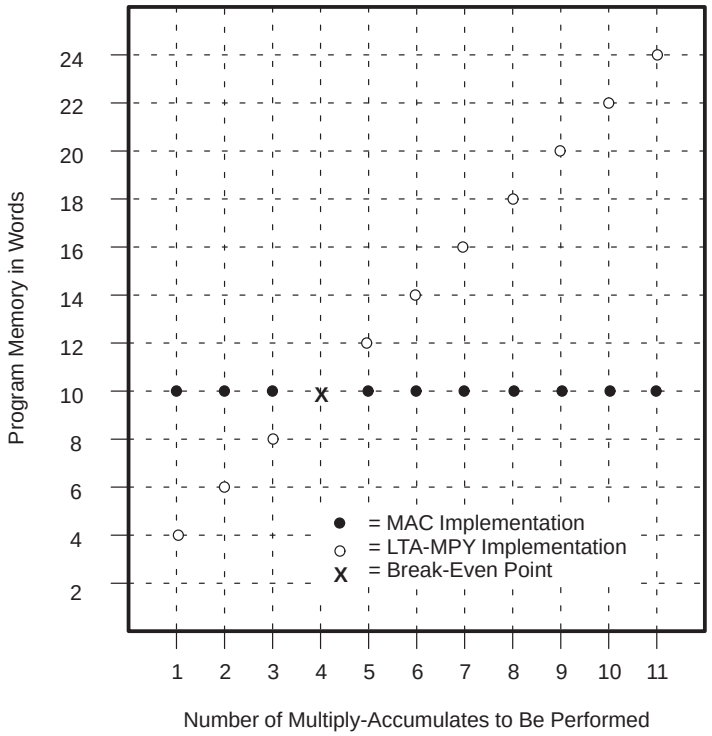


Figure 5–12. Program Memory vs. Number of Multiply-Accumulates



In numerical analysis, it is often necessary to square numbers as well as add or subtract. The TMS320C2x has two instructions, SQRA and SQRS, that accomplish this in a single machine cycle. The result of the previous operation in the PR is first added to the accumulator if SQRA is used, or subtracted from the accumulator if SQRS is used. Then the data value addressed is squared, and the result is stored in the PR. Example 5–32 uses the SQRA instruction to perform the computation.

Example 5–32. Using SQRA

```
*  THIS ROUTINE USES THE SQRA INSTRUCTION TO COMPUTE THE SQUARE OF THE DISTANCE
*  BETWEEN TWO POINTS WHERE D**2 IS DEFINED AS FOLLOWS:
*
*  D**2 = (XA – XB)**2 + (YA – YB)**2
*
DIST  LAC    XA
      SUB    XB
      SACL   XT                ; XT = XA – XB
*
      LAC    YA
      SUB    YB
      SACL   YT                ; YT = YA – YB
*
      SQRA   XT                ; (P) = XT**2
      ZAC                      ; (ACC) = 0
      SQRA   YT                ; (P) = YT**2, (ACC) = XT**2
      APAC                     ; (ACC) = XT**2 + YT**2 = D**2
*
      RET                      ; RETURN TO MAIN PROGRAM.
```

When performing multiply-and-accumulate operations, you may choose to shift the product before adding it to the accumulator. You can do both simultaneously with the MAC instruction by using the product shift mode on the TMS320C2x. This mode, controlled by two bits in the PM field of status register ST1, shifts the value from the PR while it is transferred to the accumulator. The contents of the PR are not shifted.

5.6.6 Division

Division is implemented on the TMS320C2x by repeated subtractions using SUBC, a special conditional subtract instruction. Given a 16-bit positive numerator and denominator, the repetition of the SUBC command 16 times produces a 16-bit quotient in the low accumulator and a 16-bit remainder in the high accumulator.

SUBC implements binary division in the same manner as is commonly done in long division. The numerator is shifted until subtracting the denominator no longer produces a negative result. For each subtraction that does not produce a negative answer, a one is put in the LSB of the quotient and then shifted. The shifting of the remainder and quotient after each subtraction produces the separation of the quotient and remainder in the low and high halves of the accumulator.

There are similarities between long division and the SUBC method of division. Both methods are used to divide 33 by 5 in Example 5–33.

The condition of the denominator, less than the shifted numerator, is determined by the sign of the result; both the numerator and denominator must be positive when you use the SUBC command. Thus, you must determine the sign of the quotient and compute the quotient with the absolute value of the numerator and denominator.

Integer and fractional division can be implemented with the SUBC instruction as shown in Example 5–34 and Example 5–35, respectively. When you implement a divide algorithm, it is important to know if the quotient can be represented as a fraction and the degree of accuracy to which the quotient is to be computed. For integer division, the absolute value of the numerator must be greater than the absolute value of the denominator. For fractional division, the absolute value of the numerator must be less than the absolute value of the denominator.

Example 5–33. Divide 33 by 5

Long Division:

```
                    000000000000110      Quotient
0000000000000101  )000000000100001
                  –101
                    110
                  –101
                     11      Remainder
```

SUBC Method:

32 HIGH ACC	LOW ACC 0		Comment
0000000000000000	0000000000100001	(1)	Numerator is loaded into ACC. The denominator is left-shifted 15 and subtracted from ACC. The subtraction is negative, so discard the result and shift the ACC left one bit.
–10	1000000000000000		
–10	0111111111011111		
0000000000000000	0000000001000010	(2)	2nd subtract produces negative answer, so discard result and shift ACC (numerator) left.
–10	1000000000000000		
–10	0111111110111110		
•	•		•
•	•		•
•	•		•
0000000000000100	0010000000000000	(14)	14th SUBC command. The result is positive. Shift result left and replace LSB with 1.
–10	1000000000000000		
0000000000000001	1010000000000000		
0000000000000011	0100000000000001	(15)	Result is again positive. Shift result left and replace LSB with 1.
–10	1000000000000000		
0000000000000000	11000000000000001		
0000000000000001	1000000000000011	(16)	Last subtract. Negative answer, so discard result and shift ACC left.
–10	1000000000000000		
–	1111111111111101		
0000000000000011	0000000000000110		Answer reached after 16 SUBC instructions.
Remainder	Quotient		

Example 5–34. Using SUBC for Integer Division

```
*  THIS ROUTINE IMPLEMENTS INTEGER DIVISION.
*

DN1   LT     NUMERA             ; GET SIGN OF QUOTIENT.
      MPY    DENOM
      PAC
      SACH   TEMSGN             ; SAVE SIGN OF QUOTIENT.
      LAC    DENOM
      ABS
      SACL   DENOM              ; MAKE DENOMINATOR POSITIVE.
      LAC    NUMERA             ; ALIGN NUMERATOR.
      ABS
*
*     IF denominator AND numerator ARE ALIGNED, DIVISION CAN START HERE.
*
      RPTK 15
      SUBC   DENOM              ; 16-CYCLE DIVIDE LOOP.
      SACL   QUOT
      LAC    TEMSGN
      BGEZ   DONE               ; DONE IF SIGN IS POSITIVE.
      ZAC
      SUB    QUOT
      SACL   QUOT               ; NEGATE QUOTIENT IF NEGATIVE.
DONE  LAC    QUOT
      RET                       ; RETURN TO MAIN PROGRAM.
```

Example 5–35. Using SUBC for Fractional Division

```
*  THIS ROUTINE IMPLEMENTS FRACTIONAL DIVISION.
*
DN1   LT     NUMERA             ; GET SIGN OF QUOTIENT.
      MPY    DENOM
      PAC
      SACH   TEMSGN             ; SAVE SIGN OF QUOTIENT.
      LAC    DENOM
      ABS
      SACL   DENOM              ; MAKE DENOMINATOR POSITIVE.
      ZALH   NUMERA             ; ALIGN NUMERATOR.
      ABS
*
*     IF denominator AND numerator ARE ALIGNED, DIVISION CAN START HERE.
*

      RPTK   14
      SUBC   DENOM              ; 15-CYCLE DIVIDE LOOP.
      SACL   QUOT
      LAC    TEMSGN
      BGEZ   DONE               ; DONE IF SIGN IS POSITIVE.
      ZAC
      SUB    QUOT
      SACL   QUOT               ; NEGATE QUOTIENT IF NEGATIVE.
DONE  LAC    QUOT
      RET                       ; RETURN TO MAIN PROGRAM.
```

5.6.7 Floating-Point Arithmetic

Floating-point numbers are often represented on microprocessors in a two-word format of mantissa and exponent. The mantissa is stored in one word. The exponent, the second word, indicates how many bit positions from the left the decimal point is located. If the mantissa is 16 bits, a 4-bit exponent is sufficient to express the location of the decimal point. Because of its 16-bit word size, the 16/4-bit floating-point format functions most efficiently on the TMS320C2x. The theory and implementation of floating-point arithmetic has been presented in an application report in the book, *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A).

Operations in the TMS320C2x central ALU are performed in 2s-complement fixed-point notation. To implement floating-point arithmetic, operands must be converted to fixed point for arithmetic operations, and then converted back to floating point.

Conversion to floating-point notation is performed by normalizing the input data, that is, shifting the MSB of the data word into the MSB of the internal memory word. The exponent word then indicates how many shifts are required. To multiply two floating-point numbers, the mantissas are multiplied and the exponents added. The resulting mantissa must be renormalized; since the input operands are normalized, no more than one left shift is required to renormalize the result.

Floating-point addition or subtraction requires shifting the mantissa so that the exponents of the two operands match. The difference between the exponents is used to left-shift the lower power operand before adding. Then, the output of the add must be renormalized.

TMS320C2x instructions useful in floating-point operations are the NORM, LACT, ADDT, and SUBT instructions. NORM may be used to convert fixed-point numbers to floating-point. LACT may be used to convert back to fixed-point numbers. Addition and subtraction can be computed in floating point by using ADDT and SUBT.

Example 5–36 shows a floating-point multiply on the TMS320C25. The mantissas are assumed to be in Q15 format. Q15, one of the various types of Q format, is a number representation commonly used when performing operations on noninteger numbers. In Q format, the Q number (15 in Q15) denotes how many digits are located to the right of the binary point. A 16-bit number in Q15 format, therefore, has an assumed binary point immediately to the right of the most significant bit. Since the most significant bit constitutes the sign of the number, the numbers in Q15 may take on values from +1 (represented by +0.99997...) to –1.

Example 5–36. Using NORM for Floating-Point Multiply

```
*  THIS SUBROUTINE PERFORMS A FLOATING-POINT MULTIPLY USING THE NORM INSTRUCTION.
*  THE INPUTS AND OUTPUTS ARE OF THE FORM:
*
*     C = MC * 2**EC
*
*  SINCE THE MANTISSAS, MA AND MB, ARE NORMALIZED, MC CAN BE NORMALIZED WITH A
*  LEFT SHIFT OF EITHER 0 OR 1 IN THE ACCUMULATOR. THE EXPONENT OF THE RESULT IS
*  ADJUSTED APPROPRIATELY. FOR EXAMPLE, MULTIPLICATION OF THE TWO NUMBERS A AND B,
*  WHERE A = 0.1 * 2**2 AND B = 0.1 * 2**4, PROCEEDS AS FOLLOWS:
*
*     1)     A * B = 0.01 * 2**6
*     2)     A * B = 0.1 * 2**5   (NORMALIZED RESULT)
*
MULT  LAC    EA
      ADD    EB                ; EC = EXPONENT OF RESULT BEFORE
      SACL   EC                ; NORMALIZATION.
      LT     MA
      MPY    MB
      PAC                      ; (ACC) = MA * MB
*
      SFL                      ; TAKES CARE OF REDUNDANT SIGN BIT.
      LARP   AR5
      LAR    AR5,EC            ; AR5 IS INITIALIZED WITH EC.
*
      NORM   *–                ; FINDS MSB AND MODIFIES AR5.
*
      SACH   MC                ; MC = MA * MB (NORMALIZED)
      SAR    AR5,EC
      RET                      ; RETURN TO MAIN PROGRAM.
```

Floating-point implementation programs often require denormalization as well as normalization to return results in a 16-bit format. Example 5–37 illustrates the denormalizing of numbers that were normalized with the NORM instruction. This program assumes that the mantissa is in the accumulator and that the exponent is in an auxiliary register, which is the format of the NORM instruction after execution.

Example 5–37. Using LACT for Denormalization

```
*  THIS ROUTINE DENORMALIZES NUMBERS NORMALIZED BY THE NORM INSTRUCTION (NORM *–).
*  THE DENORMALIZED NUMBER WILL BE IN THE ACCUMULATOR
*
DENORM LARP  1                ; USE AR1 TO POINT AT BLOCK B0.
       LRLK  AR1,200h
       SAR   AR4,*+           ; STORE EXPONENT AT 200h.
       SACH  *–               ; STORE MANTISSA AT 201h.
*
       LAC   *                ; LOAD ACCUMULATOR WITH EXPONENT.
       BZ    OUT              ; CHECK FOR ZERO EXPONENT.
       LT    *+
       LACT  *                ; DENORMALIZE NUMBER.
       RET                    ; RETURN TO MAIN PROGRAM.
OUT    MAR   *+               ; POINT TO MANTISSA.
       ZALH  *                ; LOAD ACCUMULATOR WITH RESULT.
       RET                    ; RETURN TO MAIN PROGRAM.
```

5.6.8 Indexed Addressing

The auxiliary register arithmetic unit (ARAU) makes it possible to calculate the next indirect address by increment/decrement or by indexed addressing in parallel to the current arithmetic operation. For example, in the multiplication of two matrices, the operation requires addressing across the rows (incrementing the address by one) or down the columns (incrementing by n). Example 5–38 gives the code for multiplying a row times a column of two 10×10 matrices. The first matrix resides in data RAM block B1, and the second matrix resides in block B0.

Example 5–38. Row Times Column

```
LARK   0,0Ah              ; SET INDEX TO 10.
LARP   1                  ; AR1 FOR ADDRESSING THE COLUMN.
LRLK   1,300h             ; POINT AR1 TO THE START OF BLOCK B1.
CNFP                      ; SET B0 TO PROG ADDRESS FOR PIPELINE.
ZAC                       ; INITIALIZE THE ACCUMULATOR.
MPYK   0                  ; CLEAR THE PRODUCT REGISTER.
RPTK   9                  ; REPEAT 10 TIMES AS MATRIX DIMENSION.
MAC    0FF00h,*0+         ; MULTIPLY ROW TIMES COLUMN.
APAC                      ; EXECUTE FINAL ACCUMULATION.
                          ; ACCUMULATOR CONTAINS PRODUCT.
```

The algorithm in Example 5–38 executes in 22 machine cycles. The key to this performance is the parallel addressing of both multiplicands simultaneously. The operation is made possible by the use of the data bus to fetch one multiplicand and the program bus to fetch the other. The auxiliary register indexes down the column of one matrix while the PC generates incremental addressing of each row of the other matrix. Each cycle of the repeat loop performs the following operations:

1) Accumulates the previous product,

2) Multiplies the row element times the column element,

3) Increments the row address, and

4) Indexes the column address.

5.6.9 Extended-Precision Arithmetic

Numerical analysis, floating-point computations, or other operations may require arithmetic to be executed with more than 32 bits of precision. Since the TMS320C2x processors are 16/32-bit fixed-point devices, software is required for the extended-precision of arithmetic operations. A subroutine that performs the extended-arithmetic function for the TMS320C25 is provided in the examples of this section. The technique consists of performing the arithmetic by parts, similar to the way in which longhand arithmetic is done.

The TMS320C25 has two features that help to make extended-precision calculations more efficient. One of the features is the carry status bit. This bit is affected by all arithmetic operations of the accumulator (ABS, ADD, ADDC, ADDH, ADDK, ADDS, ADDT, ADLK, APAC, LTA, LTD, LTS, MAC, MACD, MPYA, MPYS, NEG, SBLK, SPAC, SQRA, SQRS, SUB, SUBB, SUBC, SUBH, SUBK, SUBS, and SUBT). The carry bit is also affected by the rotate and shift accumulator instructions (ROL, ROR, SFL, and SFR) or may be explicitly modified by the load status register ST1 (LST1), reset carry (RC), and set carry (SC) instructions. For proper operation, the overflow mode bit should be reset (OVM = 0) so that the accumulator results will not be loaded with the saturation value. Note that this means that some additional code may be required if overflow of the most significant portion of the result is expected.

The carry bit is set whenever the addition of a value from the input scaling shifter or the P register to the accumulator contents generates a carry out of bit 31. Otherwise, the carry bit is reset because the carry out of bit 31 is a zero. One exception to this case is the ADDH instruction, which can only set, not reset, the carry bit. This allows the accumulation to generate the proper single carry when the addition to either the lower or upper half of the accumulator actually causes the carry. The following examples help to demonstrate the significance of the carry bit on the TMS320C25 for additions:

C	MSB							LSB	
X	F	F	F	F	F	F	F	F	ACC
+								1	
1	0	0	0	0	0	0	0	0	

C	MSB							LSB	
X	F	F	F	F	F	F	F	F	ACC
+	F	F	F	F	F	F	F	F	
1	F	F	F	F	F	F	F	E	

X	7	F	F	F	F	F	F	F	ACC
+								1	
0	8	0	0	0	0	0	0	0	

X	7	F	F	F	F	F	F	F	ACC
+	F	F	F	F	F	F	F	F	
1	7	F	F	F	F	F	F	E	

X	8	0	0	0	0	0	0	0	ACC
+								1	
0	8	0	0	0	0	0	0	1	

X	8	0	0	0	0	0	0	0	ACC
+	F	F	F	F	F	F	F	F	
1	7	F	F	F	F	F	F	F	

1	0	0	0	0	0	0	0	0	ACC
+								0	(ADDC)
0	0	0	0	0	0	0	0	1	

1	F	F	F	F	F	F	F	F	ACC
+								0	(ADDC)
1	0	0	0	0	0	0	0	0	

1	8	0	0	0	F	F	F	F	ACC
+	0	0	0	0	0	0	0	0	(ADDH)
1	8	0	0	0	F	F	F	F	

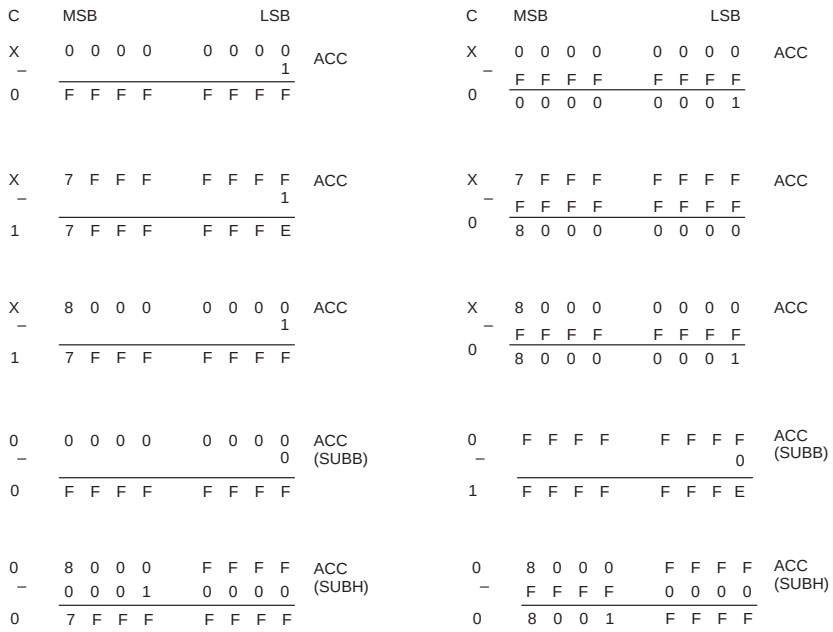
1	8	0	0	0	F	F	F	F	ACC
+	7	F	F	F	0	0	0	0	(ADH)
1	F	F	F	F	F	F	F	F	

Example 5–39 shows an implementation of two 64-bit numbers added to each other to obtain a 64-bit result. This example adds 32-bit parts and generates a carry (C) bit in the accumulator.

Example 5–39. 64-Bit Addition

```
* TWO 64-BIT NUMBERS ARE ADDED TO EACH OTHER PRODUCING A 64-BIT RESULT. THE
* NUMBERS X (X3,X2,X1,X0) AND Y (Y3,Y2,Y1,Y0) ARE ADDED RESULTING IN W
* (W3,W2,W1,W0).
*
*
*
*     X3 X2 X1 X0
*   + Y3 Y2 Y1 Y0
*     -------------
*     W3 W2 W1 W0
*
ADD64 ZALH   X1                ; ACC = X1 00
      ADDS   X0                ; ACC = X1 X0
      ADDS   Y0                ; ACC = X1 X0 + 00 Y0
      ADDH   Y1                ; ACC = X1 X0 + Y1 Y0 = W1 W0
      SACL   W0
      SACH   W1
      ZALH   X3                ; ACC = X3 00
      ADDC   X2                ; ACC = X3 X2 + C
      ADDS   Y2                ; ACC = X3 X2 + 00 Y2 + C
      ADDH   Y3                ; ACC = X3 X2 + Y3 Y2 + C = W3 W2
      SACL   W2
      SACH   W3
      RET
```

As in addition, the carry bit on the TMS320C25 is reset whenever the input scaling shifter or the P-register value subtracted from the accumulator contents generates a borrow into bit 31. Otherwise, the carry bit is set because no borrow into bit 31 is required. One exception to this case is the SUBH instruction, which can only reset the carry bit. This allows the generation of the proper single carry when the subtraction from either the lower or upper half of the accumulator actually causes the borrow. The following examples help to demonstrate the significance of the carry bit for subtractions:


C MSB LSB
X 0 0 0 0 0 0 0 0
– 1 ACC
0 F F F F F F F F
C MSB LSB
X 0 0 0 0 0 0 0 0
– F F F F F F F F ACC
0 0 0 0 0 0 0 1
X 7 F F F F F F F F
– 1 ACC
1 7 F F F F F F F E
X 7 F F F F F F F F
– F F F F F F F F ACC
0 8 0 0 0 0 0 0 0
X 8 0 0 0 0 0 0 0 0
– 1 ACC
1 7 F F F F F F F F
X 8 0 0 0 0 0 0 0 0
– F F F F F F F F ACC
0 8 0 0 0 0 0 0 0 1
0 0 0 0 0 0 0 0 0
– 0 ACC (SUBB)
0 F F F F F F F F
0 F F F F F F F F
– 0 ACC (SUBB)
1 F F F F F F F E
0 8 0 0 0 F F F F
– 0 0 0 1 0 0 0 0 ACC (SUBH)
0 7 F F F F F F F F
0 8 0 0 0 F F F F
– F F F F 0 0 0 0 ACC (SUBH)
0 8 0 0 1 F F F F

The coding in Example 5–40 shows the advantage of using the carry (C) status bit on the TMS320C25.

Example 5–40. 64-Bit Subtraction

```
* TWO 64-BIT NUMBERS ARE SUBTRACTED, PRODUCING A 64-BIT RESULT. THE NUMBER Y
* (Y3,Y2,Y1,Y0) IS SUBTRACTED FROM X (X3,X2,X1,X0) RESULTING IN W (W3,W2,W1,W0).
*
*     X3 X2 X1 X0
*   – Y3 Y2 Y1 Y0
*     -------------
*     W3 W2 W1 W0
*
SUB64 ZALH   X1                ; ACC = X1 00
      ADDS   X0                ; ACC = X1 X0
      SUBS   Y0                ; ACC = X1 X0 – 00 Y0
      SUBH   Y1                ; ACC = X1 X0 – Y1 Y0 = W1 W0
      SACL   W0
      SACH   W1
      ZALS   X2                ; ACC = 00 X2
      SUBB   Y2                ; ACC = 00 X2 – 00 Y2 – C
      ADDH   X3                ; ACC = X3 X2 – 00 Y2 – C
      SUBH   Y3                ; ACC = X3 X2 – Y3 Y2 – C = W3 W2
      SACL   W2
      SACH   W3
      RET
```

The second feature of the TMS320C25 that assists in extended-precision calculations is the MPYU (unsigned multiply) instruction. The MPYU instruction allows two unsigned 16-bit numbers to be multiplied and the 32-bit result to be placed in the product register in a single cycle. Efficiency is gained by generating partial products from the 16-bit portions of a 32-bit or larger value instead of having to split the value into 15-bit or smaller parts.

Example 5–41 shows the implementation of multiplying two 32-bit numbers to obtain a 64-bit result. The advantage in using the MPYU instruction can be observed when executed on the TMS320C25.

Example 5–41. 32 × 32-Bit Multiplication

```
*  TWO 32-BIT NUMBERS ARE MULTIPLIED, PRODUCING A 64-BIT RESULT. THE NUMBERS X
*  (X1,X0) AND Y (Y1,Y0) ARE MULTIPLIED RESULTING IN W (W3,W2,W1,W0).
*
*           X1 X0
*        x  Y1 Y0
*     --------------
*           X0*Y0
*        X1*Y0
*        X0*Y1
*     X1*Y1
*     -----------
*     W3  W2 W1  W0
*
* DETERMINE THE SIGN OF THE PRODUCT.
*
MPY32 ZALS  X1                ; ACCL = S X X  X XX X  XX X X  XX X X
X
      XOR   Y1                ; ACCL = S - -  - --- -  -- - -  -- - -
-
      SACH  SIGN,1            ; SAVE THE PRODUCT SIGN 0 = +, 1 = –.

*
*  TAKE THE ABSOLUTE VALUE OF BOTH X AND Y.
*
ABSX  ZALH  X1                ; ACC = X1 00
      ADDS  X0                ; ACC = X1 X0
      ABS
      SACH  X1                ; SAVE | X1 |.
      SACL  X0                ; SAVE | X0 |.
ABSY  ZALH  Y1                ; ACC = Y1 00
      ADDS  Y0                ; ACC = Y1 Y0
      ABS
      SACH  Y1                ; SAVE | Y1 |.
      SACL  Y0                ; SAVE | Y0 |.
*
*  MULTIPLY |X| AND |Y| TO PRODUCE | W |.
*
MULT  LT    X0                ; T = X0
      MPYU  Y0                ; T = X0, P = X0*Y0
      SPL   W0                ; SAVE | W0 |.
      SPH   W1                ; SAVE PARTIAL | W1 |.
      MPYU  Y1                ; T = X0, P = X0*Y1
      LTP   X1                ; T = X1, P = X0*Y0, ACC = X0*Y1
      MPYU  Y0                ; T = X1, P = X1*Y0, ACC = X0*Y1
      ADDS  W1                ; T = X1, P = X1*Y0,
```

```
*                                ; ACC = X0*Y1 + X0*Y0*2**-16
      MPYA   Y1                  ; T = X1, P = X1*Y1,
*                                ; ACC = X1*Y0 + X0*Y1 + X0*Y0*2**-16
      SACL   W1                  ; SAVE |W1 |.
      SACH   W2                  ; SAVE PARTIAL |W2 |.
      ZALS   W2                  ; P = X1*Y1,
*                                ; ACC = (X1*Y0 + X0*Y1)*2**-16
      BNC    SUM                 ; TEST FOR CARRY FROM W2.
      ADDH   ONE
SUM   APAC                       ; ACC = X1*Y1 + (X1*Y0 + X0*Y1)*2**-16
      SACL   W2                  ; SAVE | W2 |.
      SACH   W3                  ; SAVE | W3 |.
*
*  TEST THE SIGN OF THE PRODUCT; NEGATE IF NEGATIVE.
*
      LAC    SIGN
      BZ     DONE                ; RETURN IF POSITIVE.
*
      ZALH   W1                  ; ACC = | W1  00 |
      ADDS   W0                  ; ACC = | W1  W0 |
      CMPL
      ADD    ONE                 ; ACC = W1 W0 AND CARRY GENERATION
      SACL   W0                  ; SAVE W0.
      SACH   W1                  ; SAVE W1.
      ZALS   W2                  ; ACC = | 00  W2 |
      ADDH   W3                  ; ACC = | W3  W2 |
      CMPL
      ADDC   ZERO                ; ACC = W3 W2
      SACL   W2                  ; SAVE | W2 |.
      SACH   W3                  ; SAVE | W3 |.
DONE  RET
```

5.7 Application-Oriented Operations

The TMS320C2x efficiently implements many common digital signal processing algorithms. The architecture discussed in Chapter 3 supports features that solve numerically intensive problems usually characterized by multiply/accumulates. Some device-specific features that aid in the implementation of specific algorithms include companding, filtering, Fast Fourier Transforms (FFT), and PID control. These applications require I/O performed either in parallel or serial. Hardware requirements for I/O are discussed in Chapters 3 and 6.

5.7.1 Companding

In the area of telecommunications, one of the primary concerns is the I/O bandwidth in the communications channel. One way to minimize this bandwidth is by companding (COMpress/exPAND). Companding is defined by two international standards, A-law and μ-law, both based on the compression of the equivalent of 13 bits of dynamic range into an 8-bit code. The standard employed in the United States and Japan is μ-law; the European standard is A-law. Detailed descriptions and code examples of both types are presented in an application report on companding routines included in the book, *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A).

The technique of companding allows the digital sample information corresponding to a 13-bit dynamic range to be transmitted as 8-bit data. For processing in the TMS320C2x, it is necessary to convert the 8-bit (logarithmic) sign-magnitude data to a 16-bit 2s-complement (linear) format. Prior to output, the linear result must be converted to the compressed or companded format. Table lookup or conversion subroutines may be used to implement these functions.

Software routines for μ-law and A-law companding, flowcharts, companding algorithms, and detailed descriptions are provided in the application report on companding routines mentioned above. The algorithm space and time requirements for μ-law and A-law companding on the TMS320C25 are given in Table 5–1.

Table 5–1. Program Space and Time Requirements for μ-/A-Law Companding

Function	Memory Words		Program Cycles		Time (μs) Required†
	Program	Data	Initialization	Loop ‡	TMS320C25
μ-Law:					
Compression	74	8	19	45	4.5
Expansion	276	2	14	5	0.5
A-Law:					
Compression	100	8	19	50	5
Expansion	276	2	14	5	0.5

† Assuming initialization
‡ Worst case

In expanding from the 8-bit data to the 13-bit linear representation, table look-up is very effective because the table length is only 256 words. This is especially true for a microcomputer design because the TMS320C25 has 4K words of mask-programmable ROM, and the TMS320E25 has 4K words of EPROM. The table lookup technique requires three instructions (four words of program memory), one data memory location, 256 words of table memory, and seven instruction cycles (program in on-chip ROM) to execute.

```
LAC   SAMPLE          ;LOAD 8-BIT DATA.
ADLK  MUTABL          ;ADD THE CONVERSION TABLE BASE ADDRESS.
TBLR  SAMPLE          ;READ THE CORRESPONDING LINEAR VALUE.
```

The above conversion could be programmed as a subroutine. This would eliminate the need for a table but would increase execution time and require additional data memory locations.

When the output data has been determined in a system transmitting companded data, a compression of the data must be performed. The compression reduces the data back to the 8-bit format. Unless memory for a table of length 16384 is acceptable, the table lookup approach must be abandoned for conversion routines. Details of these implementations may be found in the application report on companding.

Access to new companding code as it becomes available is provided via the TMS320 DSP Bulletin Board Service. The bulletin board contains TMS320 source code from application reports included in *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A). See the T*MS320 Family Development Support Reference Guide* (literature number SPRU011A) for information on how to access the bulletin board.

5.7.2 FIR/IIR Filtering

Digital filters are a common requirement for digital signal processing systems. The filters fall into two basic categories: finite impulse response (FIR) and Infinite impulse response (IIR) filters. For either category of filter, the coefficients of the filter (weighting factors) may be fixed or adapted during the course of the signal processing. Presented in *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A), an application report discusses the theory and implementation of digital filters.

The 100-ns instruction cycle time of the TMS320C25 reduces the execution time of all filters—especially the IIR filters—because fewer multiply/accumulate routines are required. Correspondingly, the amount of data memory for samples and coefficients is not usually the limiting factor. Because of sensitivity to quantization of the coefficients themselves, IIR filters are usually implemented in cascaded second-order sections. This translates to instruction code consisting of LTD-MPY instruction pairs rather than MACDs. Example 5–42 illustrates an implementation of a second-order IIR filter.

Example 5–42. Implementing an IIR Filter

```
*
*  THE FOLLOWING EQUATIONS ARE USED TO IMPLEMENT AN IIR FILTER:
*
*  d(n) = x(n) + d(n – 1)a1 + d(n – 2)a2
*  y(n) = d(n)b0 + d(n – 1)b1 + d(n – 2)b2
*
START IN     XN,PA0            ; INPUT NEW VALUE XN
      LAC    XN,15             ; LOAD ACCUMULATOR WITH XN
*
      LT     DNM1
      MPY    A1
*
      LTD    DNM2
      MPY    A2
*
      APAC
      SACH   DN,1              ; d(n) = x(n) + d(n – 1)a1 + d(n – 2)a2
      ZAC
      MPY    B2
*
      LTD    DNM1
      MPY    B1
*
      LTD    DN
      MPY    B0
*
      APAC
      SACH   YN,1              ; y(n) = d(n)b0 + d(n – 1)b1 + d(n – 2)b2
      OUT    YN,PA1            ; YN IS THE OUTPUT OF THE FILTER
```

FIR filters also benefit from the faster instruction cycle time. An FIR filter requires many more multiply/accumulates than does the IIR filter with equivalent sharpness at the cutoff frequencies and distortion and attenuation in the passbands and stopbands. The TMS320C2x can help solve this problem by making longer filters feasible to implement. This is accomplished by allowing the coefficients to be fetched from program memory at the same time as a sample is being fetched from data memory. The simple implementation of this process uses the MACD instruction with the RPT/RPTK instruction.

```
RPTK  255
MACD  COEFFP,*–
```

The coefficients on the TMS320C25 may be stored anywhere in program memory (reconfigurable on-chip RAM, on-chip ROM, or external memories). When the coefficients are stored in on-chip ROM or externally, the entire on-chip data RAM may be used to store the sample sequence. Ultimately, this allows filters of up to 512 taps to be implemented on the TMS320C25. The filter executes at full speed or 100 ns per tap as long as the memory supports full-speed execution.

5.7.3 Adaptive Filtering

With FIR/IIR filtering, the filter coefficients may be fixed or adapted. If the coefficients are adapted or updated with time, then another factor impacts the computational capacity. This factor is the requirement to adapt each of the coefficients, usually with each sample. The MPYA or MPYS and ZALR instructions on the TMS320C25 aid with this adaptation to reduce the execution time.

A means of adapting the coefficients on the TMS320C2x is the least-mean-square (LMS) algorithm given by the following equation:

$$b_k\,(i+1) = b_k(i) + 2B\,e(i) \times (i-k)$$

$$\text{where } e(i) = x(i) - y(i)$$

$$\text{and } y(i) = \sum_{K=0}^{N-1} b_k x(i-k)$$

Quantization errors in the updated coefficients can be minimized if the result is obtained by rounding rather than truncating. For each coefficient in the filter at a given point in time, the factor 2*B*e(i) is a constant. This factor can then be computed once and stored in the T register for each of the updates. Thus, the computational requirement has become one multiply/accumulate plus rounding. Without the new instructions, the adaptation of each coefficient is five instructions corresponding to five clock cycles. This is shown in the following instruction sequence:

```
LRLK   AR2,COEFFD ; LOAD ADDRESS OF COEFFICIENTS.
LRLK   AR3,LASTAP ; LOAD ADDRESS OF DATA SAMPLES.
LARP   AR2
LT     ERRF       ; errf = 2*B*e(i)
.
.
.
ZALH   *,AR3      ; ACC = bk(i)*2**16
ADD    ONE,15     ; ACC = bk(i)*2**16 + 2**15
MPY    *–,AR2
APAC              ; ACC = bk(i)*2**16 + errf*x(i – k) + 2**15
SACH   *+         ; SAVE bk(i + 1).
.
.
.
```

When the MPYA and ZALR instructions on the TMS320C25 are used, the adaptation reduces to three instructions corresponding to three clock cycles, as shown in the following instruction sequence. Note that the processing order has been slightly changed to incorporate the use of the MPYA instruction. This is due to the fact that the accumulation performed by the MPYA is the accumulation of the previous product.

```
LRLK   AR2,COEFFD ; LOAD ADDRESS OF COEFFICIENTS.
LRLK   AR3,LASTAP ; LOAD ADDRESS OF DATA SAMPLES.
LARP   AR2
LT     ERRF       ; errf = 2*B*e(i)
.
.
.
ZALR   *,AR3      ; ACC = bk(i)*2**16 + 2**15
MPYA   *–,AR2     ; ACC = bk(i)*2**16 + errf*x(i – k) + 2**15
                  ; PREG = errf*x(i – k + 1)
SACH   *+         ; SAVE bk(i + 1).
.
.
.
```

Example 5–43 shows a routine to filter a signal and update the coefficients. Example 5–44 provides the conclusion to the adaptive FIR filter routine for the TMS320C25.

Adaptive filter length is restricted both by execution time and memory. Due to the adaptation, there is more processing to be completed per sample , and the adaptation itself dictates that the coefficients be stored in the reconfigurable block of on-chip RAM. Thus, the practical limit of an adaptive filter with no external data memory is 256 taps.

Example 5–43. 256-Tap Adaptive FIR Filter

```
   .title 'ADAPTIVE FILTER'
   .def ADPFIR
   .def X,Y
*
*  THIS 256-TAP ADAPTIVE FIR FILTER USES ON-CHIP MEMORY BLOCK B0 FOR COEFFICIENTS
*  AND BLOCK B1 FOR DATA SAMPLES. THE NEWEST INPUT SHOULD BE IN MEMORY LOCATION X
*  WHEN CALLED. THE OUTPUT WILL BE IN MEMORY LOCATION Y WHEN RETURNED. ASSUME THAT
*  THE DATA PAGE IS 0 WHEN THE ROUTINE IS CALLED.
*
COEFFP .set  0FF00h             ; B0 PROGRAM MEMORY ADDRESS
COEFFD .set  0200h              ; B0 DATA MEMORY ADDRESS
*
ONE    .set  7Ah                ; CONSTANT ONE (DP = 0)
BETA   .set  7Bh                ; ADAPTATION CONSTANT (DP = 0)
ERR    .set  7Ch                ; SIGNAL ERROR (DP = 0)
ERRF   .set  7Dh                ; ERROR FUNCTION (DP = 0)
Y      .set  7Eh                ; FILTER OUTPUT (DP = 0)
X      .set  7Fh                ; NEWEST DATA SAMPLE (DP = 0)
FRSTAP .set  0300h              ; NEXT NEWEST DATA SAMPLE
LASTAP .set  03FFh              ; OLDEST DATA SAMPLE
       .text
*
*
FINITE IMPULSE RESPONSE (FIR) FILTER.
*
ADPFIR CNFP                     ; CONFIGURE B0 AS PROGRAM:
       MPYK  0                  ; Clear the P register.
       LAC   ONE,14             ; Load output rounding bit.
       LARP  AR3
       LRLK  AR3,LASTAP         ; Point to the oldest sample.
FIR    RPTK  255
       MACD  COEFFP,*–          ; 256-tap FIR filter.
       CNFD                     ; CONFIGURE B0 AS DATA:
       APAC
       SACH  Y,1                ; Store the filter output.
       NEG
       ADD   X,15               ; Add the newest input.
       SACH  ERR,1              ; err(i) = x(i) – y(i)
*
* LMS ADAPTATION OF FILTER COEFFICIENTS.
*
       LT    ERR
       MPY   BETA
       PAC                      ; errf(i) = beta * err(i)
       ADD   ONE,14             ; ROUND THE RESULT.
       SACH  ERRF,1
*
       MAR   *+
       LAC   X                  ; INCLUDE NEWEST SAMPLE.
       SACL  *
*
       LRLK  AR2,COEFFD         ; POINT TO THE COEFFICIENTS.
       LRLK  AR3,LASTAP         ; POINT TO THE DATA SAMPLES.
       LT    ERRF
       MPY   *–,AR2             ; P = 2*beta*err(i)*x(i–255)
```

Example 5–44. Adaptive Filter Routine Concluded

```
*
ADAPT  ZALR  *,AR3              ; LOAD ACCH WITH b255(i) & ROUND.
       MPYA  *–,AR2             ; b255(i + 1) = b255(i) + P
*                               ; P = 2*beta*err(i)*x(i–254)
       SACH  *+                 ; STORE b255(i + 1).
*
       ZALR  *,AR3              ; LOAD ACCH WITH b254(i) & ROUND.
       MPYA  *–,AR2             ; b254(i + 1) = b254(i) + P
*                               ; P = 2*beta*err(i)*x(i–253)
       SACH  *+                 ; STORE b254(i + 1).
*
       ZALR  *,AR3              ; LOAD ACCH WITH b253(i) & ROUND.
       MPYA  *–,AR2             ; b253(i + 1) = b253(i) + P
*                               ; P = 2*beta*err(i)*x(i–252)
       SACH  *+                 ; STORE b253(i + 1).
       .
       .
       ZALR  *,AR3              ; LOAD ACCH WITH b1(i) & ROUND.
       MPYA  *–,AR2             ; b1(i + 1) = b1(i) + P
*                               ; P = 2*beta*err(i)*x(i – 0)
       SACH  *+                 ; STORE b1(i + 1).
*
       ZALR  *                  ; LOAD ACCH WITH b0(i) & ROUND.
       APAC                     ; b0(i + 1) = b0(i) + P
       SACH  *+                 ; STORE b0(i + 1).
*
       RET                      ; RETURN TO CALLING ROUTINE.
```

Table 5–2 provides data memory, program memory, and CPU cycles for a 256-tap adaptive FIR filter implementation using the TMS320C25. Note that n = 256 in the table.

Table 5–2. 256-Tap Adaptive Filtering Memory Space and Time Requirements

Device	Words In Memory		CPU Cycles
	Data	Program	
TMS320C25	5 + 2n	30 + 3n	33 + 4n

5.7.4 Fast Fourier Transforms (FFT)

Fourier transforms are an important tool used often in digital signal processing systems. The purpose of the transform is to convert information from the time domain to the frequency domain. The inverse Fourier transform converts information back to the time domain from the frequency domain. Implementations of Fourier transforms that are computationally efficient are known as Fast Fourier Transforms (FFTs). The theory and implementation of FFTs has been discussed in an application report in the book, *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A).

The TMS320C25 reduces the execution time of all FFTs by virtue of its 100-ns instruction cycle time. In addition to the shorter cycle time, an addressing feature has been added to the TMS320C25, which provides execution speed and program memory enhancements for radix-2 FFTs. As demonstrated in Figure 5–13 and Figure 5–14, the inputs or outputs of an FFT are not in sequential order—that is, they are scrambled. The scrambling of the data addressing is a direct result of the radix-2 FFT derivation. Observation of the figures and the relationship of the input and output addressing in each case reveal that the address indexing is a bit-reversed order, as shown in Table 5–3. As a result, either the data input sequence or the data output sequence must be scrambled in association with the execution of the FFT.

Figure 5–13. An In-Place DIT FFT With In-Order Outputs and Bit-Reversed Inputs

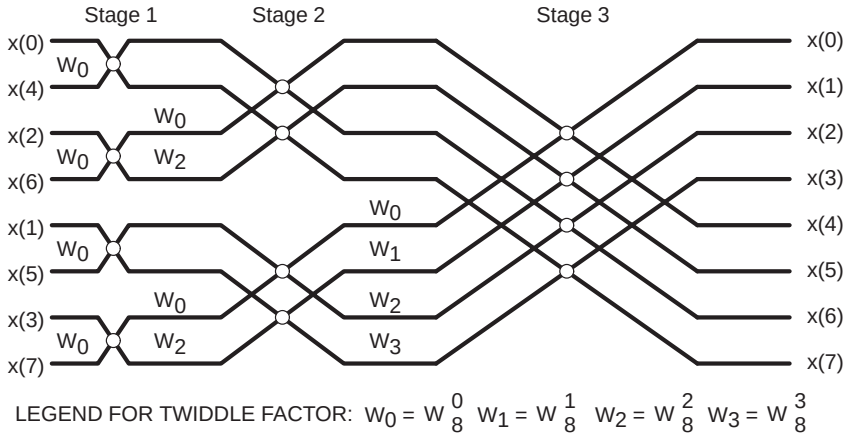


Figure 5–14. An In-Place DIT FFT With In-Order Inputs but Bit-Reversed Outputs

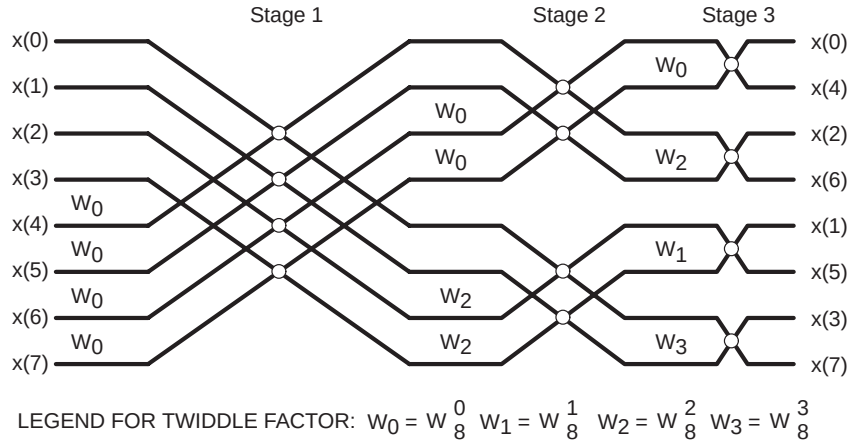


Table 5–3. Bit-Reversal Algorithm for an 8-Point Radix-2 DIT FFT

Index	Bit Pattern	Bit-reversed Pattern	Bit-reversed Index
0	000	000	0
1	001	100	4
2	010	010	2
3	011	110	6
4	100	001	1
5	101	101	5
6	110	011	3
7	111	111	7

An addressing feature that uses reverse carry-bit propagation allows the TMS320C25 to scramble the inputs or outputs while it is performing the I/O. The addressing mode is part of the indirect addressing implemented with the auxiliary registers and the associated arithmetic unit. In this mode (a derivative of indexed addressing), a value (index) contained in AR0 is either added to or subtracted from the auxiliary register being pointed to by the ARP. However, the carry bit is propagated in the reverse direction rather than the forward direction. The result is a scrambling in the address access.

The procedure for generating the bit-reversal address sequence is to load AR0 with a value corresponding to one-half the length of the FFT and to load another auxiliary register, for example, AR1, with the base address of the data array. Implementations of FFTs involve complex arithmetic; as a result, there are two data memory locations (one real and one imaginary) associated with every data sample. Generally, the samples are stored in memory in pairs with the real part in the even address locations and the imaginary part in the odd address location. This means that the offset from the base address for any given sample is twice the sample index. Real input data is easily transferred into the data memory and stored in the scrambled order, with every other location in the data memory representing the imaginary part of the data.

The following list shows the contents of auxiliary register AR1 when AR0 is initialized with a value of 8 (8-point FFT) and when data is being transferred by the code that follows.

```
        MSB                                   LSB
AR0:    0 0 0 0   0 0 0 0   0 0 0 0   1 0 0 0   8-Point FFT
AR1     0 0 0 0   0 0 1 0   0 0 0 0   0 0 0 0   Base Address

RPTK    7
IN      *BR0+,PA0
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   0 0 0 0   XR(0)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   1 0 0 0   XR(4)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   0 1 0 0   XR(2)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   1 1 0 0   XR(6)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   0 0 1 0   XR(1)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   1 0 1 0   XR(5)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   0 1 1 0   XR(3)
AR1:    0 0 0 0   0 0 1 0   0 0 0 0   1 1 1 0   XR(7)
```

Example 5–45 consists of lists of macros used in the implementation of FFTs.

Example 5–45. FFT Macros

```
COMBO  $MACRO              R1,I1,R2,I2,R3,I3,R4,I4
*  CALCULATE PARTIAL TERMS FOR R3, R4, I3, AND I4.
       LAC   :R3:,14             ; ACC    : = (1/4) (R3)
       ADD   :R4:,14             ; ACC    : = (1/4) (R3 + R4)
       SACH  :R3:,1              ; R3     : = (1/2) (R3 + R4)
       SUB   :R4:,15             ; ACC    : = (1/4) (R3 + R4)–(1/2)(R4)
       SACH  :R4:,1              ; R4     : = (1/2) (R3 – R4)
       LAC   :I3:,14             ; ACC    : = (1/4) (I3)
       ADD   :I4:,14             ; ACC    : = (1/4) (I3 + I4)
       SACH  :I3:,1              ; I3     : = (1/2) (I3 + I4)
       SUB   :I4:,15             ; ACC    : = (1/4) (I3 + I4)–(1/2)(I4)
       SACH  :I4:,1              ; I4     : = (1/2) (I3 – I4)
* CALCULATE PARTIAL TERMS FOR R2, R4, I2, AND I4.
       LAC   :R1:,14             ; ACC    : = (1/4) (R1)
       ADD   :R2:,14             ; ACC    : = (1/4) (R1 + R2)
       SACH  :R1:,1              ; R1     : = (1/2) (R1 + R2)
       SUB   :R2:,15             ; ACC    : = (1/4) (R1 + R2) – (1/2)(R2)
       ADD   :I4:,15             ; ACC    : = (1/4) [(R1 – R2) + (I3 – I4)]
       SACH  :R2:                ; R2     : = (1/4) [(R1 – R2) + (I3 – I4)]
       SUBH  :I4:                ; ACC    : = (1/4) [(R1 – R2) – (I3 – I4)]
       DMOV  :R4:                ; I4     : = R4 = (1/2)(R3–R4)
       SACH  :R4:                ; R4     : = (1/4) (R1 – R2) – (I3 – I4)]
       LAC   :I1:,14             ; ACC    : = (1/4) (I1)
       ADD   :I2:,14             ; ACC    : = (1/4) (I1 + I2)
       SACH  :I1:,1              ; I1     : = (1/2) (I1 + I2)
       SUB   :I2:,15             ; ACC    : = (1/4) (I1 + I2) – (1/2) (I2)
       SUB   :I4:,15             ; ACC    : = (1/4) [(I1 – I2) – (I3 – I4)]
       SACH  :I2:                ; I2     : = (1/4) [(I1 – I2) – (I3 – I4)]
       ADDH  :I4:                ; ACC    : = (1/4) [(I1 – I2) + (I3 – I4)]
       SACH  :I4:                ; 14     : = (1/4) [(I1 – I2) + (I3 – I4)]
* CALCULATE PARTIAL TERMS FOR R1, R3, I1, AND I3.
       LAC   :R1:,15             ; ACC    : = (1/4) (R1+R2)
       ADD   :R3:,15             ; ACC    : = (1/4) [(R1 + R2) + (R3 + R4)]
       SACH  :R1:                ; R1     : = (1/4) [(R1 + R2) + (R3 + R4)]
       SUBH  :R3:                ; ACC    : = (1/4) [(R1 + R2) – (R3 + R4)]
       SACH  :R3:                ; R3     : = (1/4) [(R1 + R2) – (R3 + R4)]
       LAC   :I1:,15             ; ACC    : = (1/4) (I1 + I2)
       ADD   :I3:,15             ; ACC    : = (1/4) [(I1 + I2) + (I3 + I4)]
       SACH  :I1:                ; I1     : = (1/4) [(I1 + I2) + (I3 + I4)]
       SUBH  :I3:                ; ACC    : = (1/4) [(I1 + I2) – (I3 + I4)]
       SACH  :I3:                ; I3     : = (1/4) [(I1 + I2) – (I3 + I4)]
       $END
ZERO   $MACRO       PR,PI,QR,QI
* CALCULATE Re[P+Q] AND Re[P–Q]
       LAC   :PR:,15             : ACC    : = (1/2) (PR)
       ADD   :QR:,15             ; ACC    : = (1/2) (PR + QR)
       SACH  :PR:                ; PR     : = (1/2) (PR + QR)
       SUBH  :QR:                ; ACC    : = (1/2) (PR + QR) – (QR)
       SACH  :QR:                ; QR     : = (1/2) (PR – QR)
       SUBH  :QI:                ; ACC    : = (1/2) (PI + QI) – (QI)
       SACH  :QI:                ; QI     : = (1/2) (PI – QI)
       $END
PIBY4  $MACRO      PR,PI,QR,QI,W
* CALCULATE Im[P+Q] AND Im[P–Q]
       LAC   :PI:,15             ; ACC    : = (1/2) (PI)
       ADD   :QI:,15             ; ACC    : = (1/2) (PI + QI)
       SACH  :PI:                ; PI     : = (1/2) (PI + QI)
       LT    :W:                 ; T REGISTER : = W = COS(PI/4) = SIN(PI/4)
       LAC   :QI:,14             ; ACC    : = (1/4) (QI)
       SUB   :QR:,14             ; ACC    : = (1/4) (QI – QR)
```

Example 5–45. FFT Macros (Continued)

```
      SACH   :QI:,1             ; QI     : = (1/2) (QI – QR)
      ADD    :QR:,15            ; ACC    : = (1/4) (QI + QR)
      SACH   :QR:,1             ; QR     : = (1/2) (QI + QR)
      LAC    :PR:,14            ; ACC    : = (1/4) (PR)
      MPY    :QR:               ; P REGISTER : = (1/4) (QI – QR) *W
      APAC                      ; ACC    : = (1/4) [PR + (QI + QR) *W]
      SACH   :PR:,1             ; PR     : = (1/2) [PR + (QI + QR) *W]
      SPAC                      ; ACC    : = (1/4) (PR)
      SPAC                      ; ACC    : = (1/4) [PR – (QI + QR) *W]
      SACH   :QR:,1             ; QR     : = (1/2) [PR – (QI + QR) *W]
      LAC    :PI:,14            ; ACC    : = (1/4) (PI)
      MPY    :QI:               ; P REGISTER : = (1/4) (QI – QR) *W
      APAC                      ; ACC    : = (1/4) [PI + (Q1 – QR) *W]
      SACH   :PI:,1             ; PI     : = (1/2) [PI + (QI – QR) *W]
      SPAC                      ; ACC    : = (1/4) (PI)
      SPAC                      ; ACC    : = (1/4) [PI – (QI – QR) *W]
      SACH   :QI:,1             ; QI     : = (1/2) [PI – (QI – QR) *W]
      $END
PIBY2 $MACRO     PR,PI,QR,QI
* CALCULATE Re[P+jQ] AND Re[P–jQ]
      LAC    :PI:,15            ; ACC    : = (1/2) (PI)
      SUB    :QR:,15            ; ACC    : = (1/2) (PI – QR)
      SACH   :PI:               ; PI     : = (1/2) (PI – QR)
      ADDH   :QR:               ; ACC    : = (1/2) (PI – QR) + (QR)
      SACH   :QR:               ; QR     : = (1/2) (PI + QR)
* CALCULATE Im[P+jQ] AND Im[P–jQ]
      LAC    :PR:,15            ; ACC    : = (1/2) (PR)
      ADD    :QI:,15            ; ACC    : = (1/2) (PR + QI)
      SACH   :PR:               ; PR     : = (1/2) (PR + QI)
      SUBH   :QI:               ; ACC    : = (1/2) (PR + QI) – (QI)
      DMOV   :QR:               ; QR      → QI
      SACH   :QR:               ; QR     : = (1/2) (PR – QI)
      $END
PI3BY4 $MACRO PR,PI,QR,QI,W
      LT     :W:                ; T REGISTER : = W = COS (PI/4) = SIN (PI/4)
      LAC    :QI:,14            ; ACC    : = (1/4) (QI)
      SUB    :QR:,14            ; ACC    : = (1/4) (QI – QR)
      SACH   :QI:,1             ; QI     : = (1/2) (QI – QR)
      ADD    :QR:,15            ; ACC    : = (1/4) (QI + QR)
      SACH   :QR:,1             ; QR     : = (1/2) (QI + QR)
      LAC    :PR:,14            ; ACC    : = (1/4) (PR)
      MPY    :QI:               ; P REGISTER : = (1/4) (QI – QR) *W
      APAC                      ; ACC    : = (1/4) [PR + (QI – QR) *W]
      SACH   :PR:,1             ; PR     : = (1/2) [PR + (QI – QR) *W]
      SPAC                      ; ACC    : = (1/4) (PR)
      SPAC                      ; ACC    : = (1/4) [PR – (QI – QR) *W]
      MPY    :QR:               ; P REGISTER : = (1/4) (QI + QR) *W
      SACH   :QR:,1             ; QR     : = (1/2) [PR – (QI – QR) *W]
      LAC    :PI:,14            ; ACC    : = (1/4) (PI)
      SPAC                      ; ACC    : = (1/4) [PI – (QI + QR) *W]
      SACH   :PI:,1             ; PI     : = (1/2) [PI – (QI + QR) *W]
      APAC                      ; ACC    : = (1/4) (PI)
      APAC                      ; ACC    : = (1/4) [PI + (QI + QR) *W]
      SACH   :QI:,1             ; QI     : = (1/2) [PI + (QI + QR) *W]
      $END
```

Example 5–46. An 8-Point DIT FFT

```
X0R     .set  00
X0I     .set  01
X1R     .set  02
X1I     .set  03
X2R     .set  04
X2I     .set  05
X3R     .set  06
X3I     .set  07
X4R     .set  08
X4I     .set  09
X5R     .set  10
X5I     .set  11
X6R     .set  12
X6I     .set  13
X7R     .set  14
X7I     .set  15
W       .set  16
WVALUE  .set  5A82h             ; VALUE FOR SIN(45) OR COS(45)
        .text*
* INITIALIZE FFT PROCESSING.
FFT   SPM    0                  ; NO SHIFT OF PR OUTPUT
      SSXM                      ; SET SIGN-EXTENSION MODE.
      ROVM                      ; RESET OVERFLOW MODE.
      LDPK   4                  ; SET DATA PAGE POINTER TO 4.
      LALK   WVALUE             ; GET TWIDDLE FACTOR VALUE.
      SACL   W                  ; STORE SIN(45) OR COS(45).
* INPUT SAMPLES, STORING IN BIT-REVERSED ORDER.
*
      LARK   AR0,8              ; LOAD LENGTH OF FFT IN AR0.
      LRLK   AR1,200h           ; LOAD AR1 WITH DATA PAGE 4 ADDRESS.
      LARP   AR1
      RPTK   7
      IN     *BR0+,PA0          ; ONLY REAL-VALUED INPUT
*
* 1ST & 2ND STAGES COMBINED WITH DIVIDE-BY-4 INTERSTAGE SCALING.
   COMBO X0R,X0I,X1R,X1I,X2R,X2I,X3R,X3I,
   COMBO X4R,X4I,X5R,X5I,X6R,X6I,X7R,X7I.
*
* 3RD STAGE WITH DIVIDE-BY-2 INTERSTAGE SCALING.
   ZERO      X0R,X0I,X4R,X4I
   PIBY4     X1R,X1I,X5R,X5I,W
   PIBY2     X2R,X2I,X6R,X6I
   PI3BY4    X3R,X3I,X7R,X7I,W
* OUTPUT SAMPLES, SUPPLYING IN SEQUENTIAL ORDER.
      LRLK   AR1,200h           ; LOAD AR1 WITH DATA PAGE 4 ADDRESS.
      RPTK   15
      OUT    *+,PA0             ; COMPLEX-VALUED OUTPUT
      RET
```

Table 5–4 shows execution speed, program memory, and data memory for an 8-point DIT FFT implementation using the TMS320C25.

Table 5–4. FFT Memory Space and Time Requirements

Device	Words In Memory		CPU Cycles	Time (μs)
	Data	Program		
TMS320C25	17	153	178	17.8

5.7.5 PID Control

Control systems are concerned with regulating a process and achieving a desired behavior or output from the process. A control system consists of three main components: sensors, actuators, and a controller. Sensors measure the behavior of the system. Actuators supply the driving force to ensure the desired behavior. The controller generates actuator commands corresponding to the error conditions observed by the sensors and the control algorithms programmed in the controller. The controller typically consists of an analog or digital processor.

Analog control systems are usually based on fixed components and are not programmable. They are also limited to using single-purpose characteristics of the error signal, such as P (proportional), I (integral), and D (derivative), or a combination. These limitations, along with other disadvantages of analog systems, such as component aging and temperature drift, are reasons why digital control systems increasingly replace analog systems in most control applications.

Digital control systems that use a microprocessor/microcontroller are able to implement more sophisticated algorithms of modern control theory, such as state models, deadbeat control, state estimation, optimal control, and adaptive control. Digital control algorithms deal with the processing of digital signals and are similar to DSP algorithms. The TMS320C2x instruction set can therefore be used very effectively in digital control systems.

The most commonly used algorithm in both analog and digital control systems is the PID (Proportional, Integral, and Derivative) algorithm. The classical PID algorithm is given by

$$u(t) = K_p e(t) + K_i \int e dt + K_d \frac{de}{dt}$$

The PID algorithm must be converted into a digital form for implementation on a microprocessor. Using a rectangular approximation for the integral, the PID algorithm can be approximated as

$$u(n) = u(n-1) + K_1\, e(n) + K_2\, e(n-1) + K_3\, e(n-2)$$

This algorithm is implemented in Example 5–47.

Example 5–47. PID Control

```
   .title 'PID CONTROL'
   .def PID
*
*  THIS ROUTINE IMPLEMENTS A PID ALGORITHM.
*
UN .set     0                  ; OUTPUT OF CONTROLLER
E0 .set     1                  ; LATEST ERROR SAMPLE
E1 .set     2                  ; PREVIOUS ERROR SAMPLE
E2 .set     3                  ; OLDEST ERROR SAMPLE
K1 .set     4                  ; GAIN CONSTANT
K2 .set     5                  ; GAIN CONSTANT
K3 .set     6                  ; GAIN CONSTANT
   .text
*
* ASSUME DATA PAGE 0 IS SELECTED.
*
PID   IN     E0,PA0            ; READ NEW ERROR SAMPLE
      LAC    UN                ; ACC = u(n–1)
      LT     E2                ; LOAD T REG WITH OLDEST SAMPLE
      MPY    K2                ; P = K2*e(n – 2)
      LTD    E1                ; ACC = u(n – 1) + K2*e(n – 2)
      MPY    K1                ; P = K1*e(n – 1)
      LTD    E0                ; ACC = u(n – 1) + K1*e(n – 1) + K2*e(n – 2)
      MPY    K0                ; P = K0*e(n)
      APAC                     ; ACC = u(n – 1) + K0*e(n) + K1*e(n – 1)
      *                        ;      +K2*e(n – 2)
      SACH   UN,1              ; STORE OUTPUT
      OUT    UN,PA1            ; SEND IT
```

The PID loop takes 13 cycles to execute (1.3 μs at a 40-MHz clock rate). The TMS320 can also be used to implement more sophisticated algorithms, such as state modeling, adaptive control, state estimation, Kalman filtering, and optimal control. Other functions that can be implemented are noise filtering, stability analysis, and additional control loops.

Chapter 6

Hardware Applications

The TMS320C2x has the power and flexibility to satisfy a wide range of system requirements. The 128K-word address space for program and data memory can be used to interface external memories or to implement single-chip solutions. Peripheral devices can be interfaced to the TMS320C2x to perform analog signal acquisition at different levels of signal quality.

Information and examples on how to interface the TMS320C2x to external devices are presented in this section. The examples given are general enough to be adapted easily for a particular system requirement. For more detailed information, refer to the application reports included in the book, *Digital Signal Processing Applications with the TMS320 Family, Volume I* (literature number SPRA012A). Refer also to the application report, *Hardware Interfacing to the TMS320C25* (literature number SPRA014A), published separately. Appendix G discusses analog interface peripherals and their applications, and Appendix H provides listings and brief information regarding TI memories and analog conversion devices that are used in many of the applications in this chapter.

The TMS320C26 is similar to the TMS320C25 except for its internal memory configuration. This is discussed in Section 3.4 and in Appendix B.

Topics in this chapter include:

Topic **Page**

6.1 System Control Circuitry 6-2
6.2 Interfacing Memories 6-11
6.3 Direct Memory Access (DMA) 6-32
6.4 Global Memory 6-35
6.5 Interfacing Peripherals 6-37
6.6 Systems Applications 6-48

6.1 System Control Circuitry

The system control circuitry performs functions that are critical for proper system initialization and operation. A powerup reset circuit design and a crystal oscillator circuit design are presented in this chapter. The powerup reset circuit assures that a reset of the part occurs only after the oscillator is running and stabilized. This oscillator circuit allows the use of third-overtone crystals, which are readily available at frequencies above 20 MHz. For a more detailed discussion of system control circuitry, refer to the application report, *Hardware Interfacing to the TMS320C25* (literature number SPRA014A).

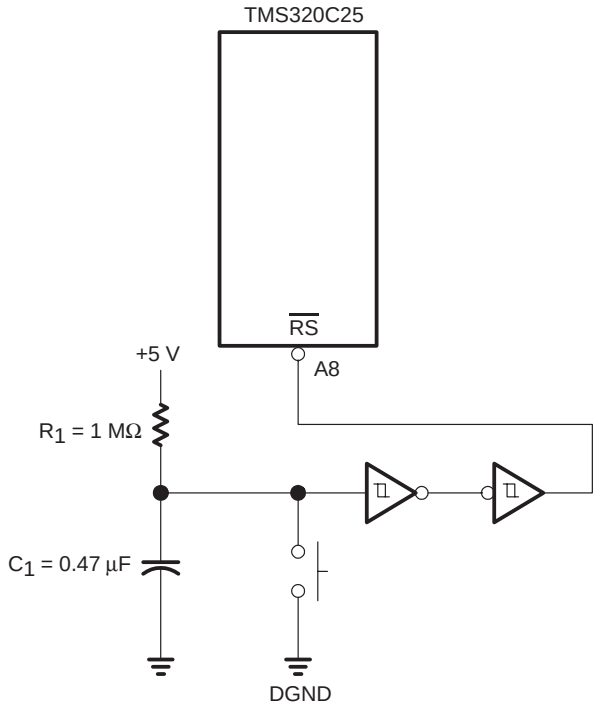
6.1.1 Powerup Reset Circuit

The reset circuit shown in Figure 6–1 performs a powerup reset, that is, the TMS320C2x is reset when power is applied. Note that the switch circuit must include debounce circuitry. Driving the $\overline{RS}$ signal low initializes the processor. Reset affects several registers and status bits (see subsection 3.6.2 for a detailed description of the effect of reset on processor status).

Note:

Reset does not have internal Schmidt hysterisis. Avoid slow rise and fall times to insure proper reset operation.

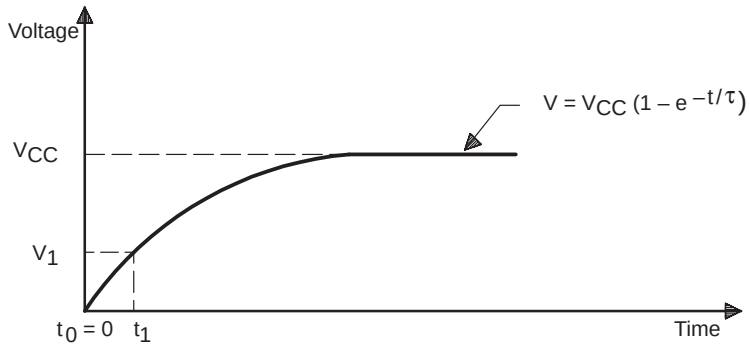
Figure 6–1. Powerup Reset Circuit



For proper system initialization, the reset signal must be applied for at least three CLKOUT cycles, that is, 300 ns for a TMS320C25 operating at 40 MHz. Upon powerup, it can take from several to hundreds of milliseconds before the system oscillator reaches a stable operating state. Therefore, the powerup reset circuit should generate a low pulse on the reset line until the oscillator is stable (that is, 100 to 200 ms).

The voltage on the reset pin $\overline{RS}$ is controlled by the R_1C_1 network (see Figure 6–1). After a reset, this voltage rises exponentially according to the time constant R1C1, as shown in Figure 6–2. The Schmidt-Trigger inverter in this case could be a 74HC14. If a TTL device were used, the low-level input current (I_{IL}) would initially cause the voltage on C_1 to rise faster than expected.

Figure 6–2. Voltage on TMS320C25 Reset Pin



The duration of the low pulse on the reset pin is approximately t_1, which is the time it takes for the capacitor C_1 to be charged to 1.5 V. This is approximately the voltage at which the reset input switches from a logic level 0 to a logic level 1. The capacitor voltage is given by

$$V = V_{CC}\left[1 - e^{-\frac{t}{\tau}}\right] \quad (1)$$

where $\tau = R_1C_1$ is the reset circuit time constant. Solving (1) for τ gives

$$t = -R_1C_1 \ln\left[1 - \frac{V}{V_{CC}}\right] \quad (2)$$

For example, setting the following:

$R_1 = 1\ M\Omega$	$V_{CC} = 5\ V$
$C_1 = 0.47\ \mu F$	$V = V_1 = 1.5\ V$

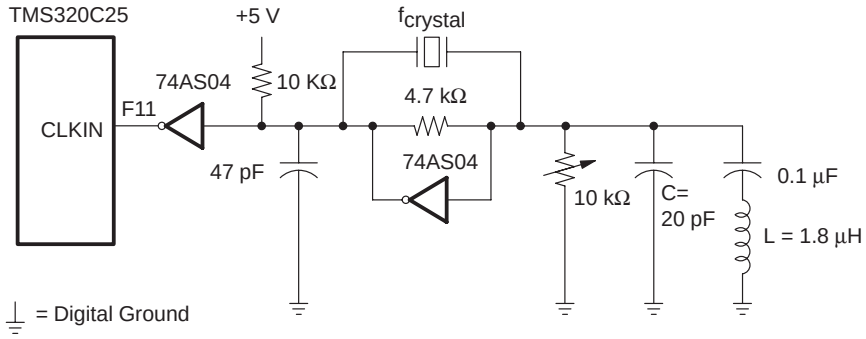
gives $t = t_1 = 167$ ms. In this case, the reset circuit of Figure 6–1 can generate a low pulse of long enough duration (167 ms) to ensure the stabilization of the oscillator upon powerup in most systems.

6.1.2 Crystal Oscillator Circuit

The crystal oscillator circuit shown in Figure 6–3 is designed to operate at 40.96 MHz. Since crystals with fundamental oscillation frequencies of 30 MHz and above are not readily available, a parallel-resonant third-overtone oscillator is used. If a packed clock oscillator is used, oscillator design is of no concern.

The master clock frequency of 40.96 MHz is chosen because it can be conveniently converted to the timing signals of interface circuits used by the communications industry. A combo-codec example is given in subsection 6.5.1.

Figure 6–3. Crystal Oscillator Circuit



The 74AS04 inverter in Figure 6–3 provides the 180-degree phase shift that a parallel oscillator requires. The 4.7-kΩ resistor provides the negative feedback that keeps the oscillator in a stable state; that is, the poles of the system are constrained in a narrow region about the jω axis of the s-plane (analog domain). The 10-kΩ potentiometer is used to bias the 74AS04 in the linear region.

In a third-overtone oscillator, the crystal fundamental frequency must be attenuated so that oscillation is at the third harmonic. This is achieved with an LC circuit that filters out the fundamental.

The impedance of the LC network must be inductive below and capacitive above the second harmonic. The impedance of the LC circuit is given by

$$z(\omega) = \frac{\frac{L}{C}}{j\left[\omega L - \frac{1}{\omega C}\right]} \qquad (3)$$

Therefore, the LC circuit has a pole at

$$\omega_p = \frac{1}{\sqrt{LC}} \qquad (4)$$

At frequencies significantly lower than ω_p , the 1/(ωC) term in (3) becomes the dominating term, while ωL can be neglected. This gives

$$z(\omega) = j\omega L \qquad \text{for } \omega << \omega_p \qquad (5)$$

In (5), the LC circuit appears inductive at frequencies lower than ω_p. On the other hand, at frequencies much higher than ω_p, the ωL term is the dominant term in (3), and 1/(ωC) can be neglected. This gives

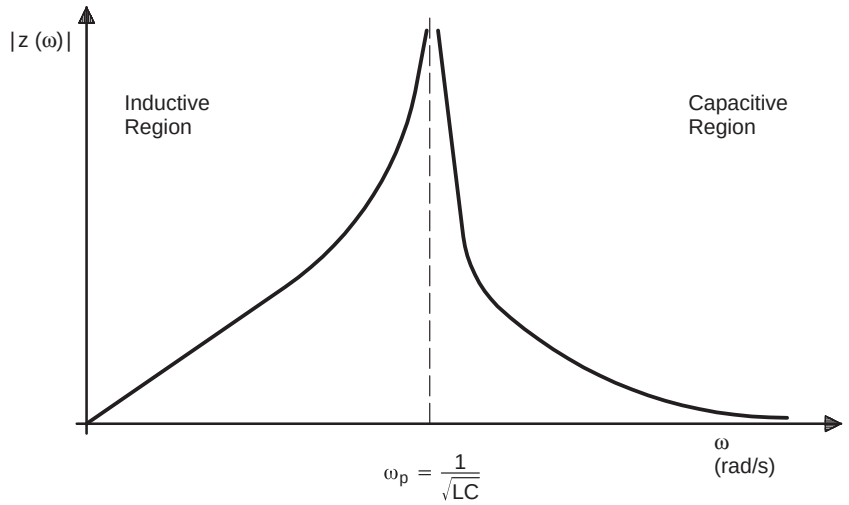
$$z(\omega) = \frac{1}{j\omega C} \qquad \text{for } \omega >> \omega_p \qquad (6)$$

The LC circuit in (6) appears increasingly capacitive as frequency increases above ω_p. This is shown in Figure 6–4, which is a plot of the magnitude of the impedance of the LC circuit of Figure 6–3 versus frequency.

Based on the discussion above, the design of the LC circuit proceeds as follows: choose the pole frequency ω_p approximately halfway between the crystal fundamental and the third harmonic. The circuit now appears inductive at the fundamental frequency and capacitive at the third harmonic.

In the oscillator of Figure 6–3, ω_p = 26.5 MHz, which is approximately halfway between the fundamental and the third harmonic; The values used in this case are determined by using C = 20 pF; then, using (4), L = 1.8 μH.

Figure 6–4. Magnitude of Impedance of Oscillator LC Network



6.1.3 User Target Design Considerations for the XDS

The architecture for the TMS320C2x emulator (XDS) maximizes speed and performance. No external serial logic levels have been added to any of the address, data, or control signals other than those added to the setup times of READY, $\overline{RS}$, $\overline{BIO}$, and $\overline{HOLD}$, and the propagation delay of $\overline{HOLDA}$ (hold acknowledge). The additional loading on outputs induced by the XDS is comprehended in the XDS and TMS320C2x device design, thus allowing the user the full drive as specified in the TMS320C2x device data sheet. The DC loading characteristics of inputs is defined in Chapter 9 of the *XDS/22 TMS320C2x Emulator User's Guide* (literature number SPDU055).

The emulator architecture works closely with the user's system design to allow the user's memory to have maximum access times. Areas of close interaction between the emulator and target system are:

- ❑ Bus control
- ❑ READY timing and memory substitution
- ❑ Reset and hold
- ❑ Miscellaneous considerations

Bus Control

When the emulator is halted from the keyboard or any of the breakpoint functions, the current state of the device being emulated is extracted by the control processor. This processor communicates with the emulated device over the emulated device's data bus. Additional communication is generated by commands entered from the keyboard.

Before communication between the control processor and the device being emulated begins, the control processor generates an interlock sequence on the emulated device's $\overline{HOLD}$ input in order to define data bus ownership. Once the target $\overline{HOLD}$ is deactivated, this interlock prevents the target system from receiving an active $\overline{HOLDA}$ until the emulator has completed accessing the processor resources. The emulator will not attempt to use the data bus until the interlock is successful, thus guaranteeing that it will not try to use the data bus when $\overline{HOLDA}$ is asserted to the target system.

When communication between the control processor and the device being emulated is complete, the hold interlock is released, and the target system can again receive hold acknowledge when $\overline{HOLD}$ is asserted. At this point, the emulator is waiting for another command from the keyboard. Communication between the device being emulated and the control process occurs when $\overline{DS}$, $\overline{PS}$, $\overline{IS}$, and $\overline{HOLDA}$ are all high.

The target system should drive the data bus only when the following conditions are met:

- $\overline{\text{HOLDA}}$ is active, or
- $\overline{\text{DS}}$, $\overline{\text{PS}}$, or $\overline{\text{IS}}$ is active and R/$\overline{\text{W}}$ is high.

The XDS hardware uses the data bus only while the above signals are inactive. When these rules are not followed, the XDS gives a PROCESSOR SYNC LOST 1160 error. This error may also be caused by signal-to-signal shorts in the target system, misalignment of the target connector, poor grounding of the target connector, or wiring errors on the target system.

READY and Memory Substitution

Because the XDS adds one internal level of 7 ns in series with the READY input, your system is left with only 10 ns to generate READY. This can be accomplished by generating READY with a 10-ns TIBPAL16R4 device. READY should be generated from $\overline{\text{DS}}$, $\overline{\text{PS}}$, or $\overline{\text{IS}}$ and the decode of the address lines.

The target system must present a valid READY high on each external access, even when using the XDS substitution memory. Suggested implementation of READY logic on the target system should hold READY high until target memory requiring wait states is addressed.

The XDS provides two types of memory substitution: fast static RAM at a fixed address and slower dynamic RAM at mappable addresses. You are is responsible for deselecting target memory residing in the same address of the emulator's fast static memory if this emulator memory is mapped in. (Note that the target should not drive the data bus on a read.) This fast static emulator substitution memory consists of 8K words of fast static RAM, which can be individually mapped in as 4K words of program memory starting at address 0000 and 4K words of data memory starting at location 0000. In this case, the target system cannot drive the data bus even though $\overline{\text{DS}}$ or $\overline{\text{PS}}$ is active. Although this emulator static RAM can operate with zero wait states, you can model target wait states by using the target READY signal. However, this requires the target system to eventually respond with a valid READY high. The emulator generates wait states until it does.

The slower dynamic RAM controls bus access through the $\overline{\text{DS}}$ or $\overline{\text{PS}}$ control signals. The target system can drive the data bus when $\overline{\text{PS}}$ or $\overline{\text{IS}}$ is asserted. Emulator logic assures that $\overline{\text{DS}}$, $\overline{\text{PS}}$, and $\overline{\text{IS}}$ are returned to their inactive state when the dynamic RAM substitution memory uses the data bus on reads.

The dynamic RAM substitution memory always uses more than one clock to return data. An access to address space mapped to the dynamic substitution memory is accompanied by the assertion of $\overline{DS}$ or $\overline{PS}$, and $\overline{STRB}$. When the target logic generates a READY high condition, the device appears to complete the memory cycle by driving $\overline{DS}$, $\overline{PS}$, $\overline{IS}$, or $\overline{STRB}$ to their inactive states at their normal switching times. The device under emulation is held not ready for at least one extra clock cycle or until the memory substitution data is available. The memory substitution data is then driven onto the data bus on reads while all bus control signals at the target connector are high.

Additional wait states can be added with the use of the target READY line. In this case, the memory control lines model the target access timing. However, the program cycle count is affected by the additional cycles internal to the emulator's access of the dynamic RAM. Since the system responds to the READY line, the target must eventually return a valid READY high on each access.

Miscellaneous Considerations

When the XDS is powered up, the device under emulation is placed in the run mode with all memory substitution turned off. The control processor does not attempt to communicate with the device under emulation until you communicate with the emulator. If the target system is asserting $\overline{RS}$, $\overline{HOLD}$, or not READY continuously to the device under emulation, the control processor cannot gain control of the device under emulation and reports a PROCESSOR SYNC LOST 1160 error. This condition can be caused by a powered-up emulator plugged into a powered-down target system. Although the $\overline{RS}$, $\overline{HOLD}$, and READY are pulled up with resistors on the emulator, the impedance of the powered-down target system can assert a control signal or load the data bus so that the XDS cannot function properly.

The conductive foam on the XDS target cable must be removed along with the foam on the logic show pod prior to XDS powerup. Failure to do so can also cause the PROCESSOR SYNC LOST 1160 error.

TMS320C25 Designs Using $\overline{HOLD}$ and $\overline{HOLDA}$. When the target system asserts $\overline{HOLD}$ active low while the emulator is processing user-invoked commands requiring access of the device-under-emulation resources, the target will not receive $\overline{HOLDA}$ until the command is complete.

When interfacing to dynamic RAM in the target system, use READY rather than $\overline{HOLD}$ to insert refresh cycles. A user-invoked command could hold off $\overline{HOLDA}$ long enough to lose charge in the dynamic cells. Likewise, if the address lines to the DRAMs are not buffered, the refresh cycle in a RAS ONLY REFRESH system could conflict with the emulator system that controls addressing during command processing.

Stack Usage. An interrupt is used to halt the device being emulated, thereby using one of the emulated device stack locations. When an XDS is to be used, the applications programmer should reserve one level of the stack for code development.

Transmission Line Phenomena. Because the XDS target cable is approximately 20 inches, use of advanced CMOS or fast/advanced Schottky TTL may cause line reflections (ringing above input thresholds) on input lines to the XDS. Series termination resistors (22 to 68 ohms) can help eliminate this problem. In some cases where significant additional signal length is added to XDS outputs, the series resistors on the XDS may not be sufficient to control reflections. In this case, additional corrective actions may be necessary.

Clock Source. The XDS does not support the use of a crystal in the target system. The emulator's clock source can be selected from three sources:

- A clock (with TTL levels) driven up the target cable on pin F11 (PGA) or pin 35 (PLCC),
- A socketed changeable crystal on the emulator board (Y1), or
- A socketed changeable canned TTL oscillator on the EMU (U9).

6.2 Interfacing Memories

The following buses, port, and control signals provide system interface to the TMS320C2x processor:

- 16-bit address bus (A15 – A0)
- 16-bit data bus (D15 – D0)
- Serial port
- $\overline{PS}$, $\overline{DS}$, $\overline{IS}$ (program, data, I/O space select)
- R/$\overline{W}$ (read/write) and $\overline{STRB}$ (strobe)
- READY and $\overline{MSC}$ (microstate complete)
- $\overline{HOLD}$ and $\overline{HOLDA}$ (hold acknowledge)
- $\overline{INT}$ (2–0) and $\overline{IACK}$ (interrupt acknowledge)
- $\overline{BIO}$ (branch control) and XF (external flag)
- $\overline{SYNC}$ (synchronization) and $\overline{BR}$ (bus request)

The TMS320C2x can be interfaced with PROMs, EPROMs, and static RAMs. The speed, cost, and power limitations imposed by a particular application determine the selection of a specific memory device. If speed and maximum throughput are desired, the TMS320C2x can run with no wait states. In this case, memory accesses are performed in a single machine cycle. Alternatively, slower memories can be accessed by introducing an appropriate number of wait states or slowing down the system clock. The latter approach is more appropriate when interfacing to memories with access times slightly longer than those required by the TMS320C2x at full speed.

When wait states are required, the number of wait states depends on the memory access time (see subsection 6.2.3). With no wait states, the READY input to the TMS320C2x can be pulled high. If one or more wait states are required, the READY input must be driven low during the cycles in which the TMS320C2x enters a wait state.

The TMS320C2x implements two separate and distinct memory spaces: program space (64K words) and data space (64K words). Distinction between the two spaces is made through the use of the $\overline{PS}$ (program space) and $\overline{DS}$ (data space) pins. A third space, the I/O space, is also available for interfacing with peripherals. This space is selected by the $\overline{IS}$ (I/O space) pin, and is discussed in Section 6.5.

The following brief discussion describes the TMS320C2x read and write cycles. For the memory read and write timing diagrams, refer to the TMS320C2x Data Sheets in Appendix A. For further information about read and write operation, see subsection 3.7.3 . Throughout this chapter, Q is used to indicate the duration of a quarter phase of the output clock (CLKOUT1 or CLKOUT2). Memory interfaces discussed in this chapter assume that the TMS320C2x is running at 40 MHz; that is, Q = 25 ns.

In a read cycle, the following sequence occurs:

1) Near the beginning of the machine cycle (CLKOUT1 goes low), the address bus and one of the memory select signals ($\overline{PS}$, $\overline{DS}$, or $\overline{IS}$) becomes valid. R/$\overline{W}$ goes high to indicate a read cycle.

2) $\overline{STRB}$ goes low no less than $t_{su(A)} = Q - 12$ ns after the address bus is valid.

3) Early in the second half of the cycle, the READY input is sampled. READY must be stable (low or high) at the TMS320C25 no later than $t_{d(SL-R)} = Q - 20$ ns after $\overline{STRB}$ goes low.

4) With no wait states (READY is high), data must be available no later than $t_{a(SL)} = t_{a(A)} - t_{su(A)} = 2Q - 23$ ns after $\overline{STRB}$ goes low.

The sequence of events that occurs during an external write cycle is the same as the above, with the following differences:

1) R/$\overline{W}$ goes low to indicate a write cycle.

2) The data bus begins to be driven approximately concurrently with $\overline{STRB}$ going low.

3) After $\overline{STRB}$ goes high, the data bus must enter a high-impedance state no later than $t_{dis(D)} = Q+15$ ns.

6.2.1 Interfacing PROMs

Program memory in a TMS320C2x system can be implemented through the use of PROMs. Two different approaches for interfacing PROMs to the TMS320C2x can be taken, depending on whether or not any of the memories in the system require wait states. When no wait states are required for any of the memories, READY can be tied high, and the interface to the PROMs becomes a direct connection. In this first approach, address decoding is not required, because the system contains only a small amount of one type of memory. When some of the system memories require wait states, address decoding must be performed to distinguish between two or more memory types with different access times. In the second approach, a valid READY signal that

meets the TMS320C2x timing requirements must be provided. An efficient method of accomplishing this is to use one section of circuitry to generate the address decode, and a second, independent section to generate the READY signal. These two approaches are discussed in this section. For more detailed information, see *Hardware Interfacing to the TMS320C25* (literature number SPRA014A).

An example of a no-wait-state memory system is the direct PROM interface design shown in Figure 6–5. In this design, the TMS320C25 is interfaced with the Texas Instruments TBP38L165-35, a low-power 2K $\times$ 8-bit PROM. The interface timing for the design of Figure 6–5 is shown in Figure 6–6. The same techniques can be used with all TMS320C2x devices.

The TMS320C25 expects data to be valid no later than 2Q–23 ns after $\overline{\text{STRB}}$ goes low. (This is 27 ns for a TMS320C25 operating at 40 MHz.) The access times of the TBP38L165-35 are 35 ns maximum from address $t_{a(A)}$, and 20 ns maximum from chip enable $t_{a(S)}$. On the TMS320C25, address becomes valid a minimum of $t_{su(A)}$ = Q–12 ns = 13 ns before $\overline{\text{STRB}}$ goes low. Therefore, the data appears on the data bus within 27 ns after $\overline{\text{STRB}}$ goes low, as required by the TMS320C25.

When a read cycle is followed by a write cycle, take care to avoid bus conflict. Bus conflict also may occur when a TMS320C25 write cycle is followed by a memory read cycle. In this case, the TMS320C25 data lines must be in a high-impedance state before the memory starts driving the data bus.

Figure 6–5. Direct Interface of TBP38L165-35 to TMS320C25

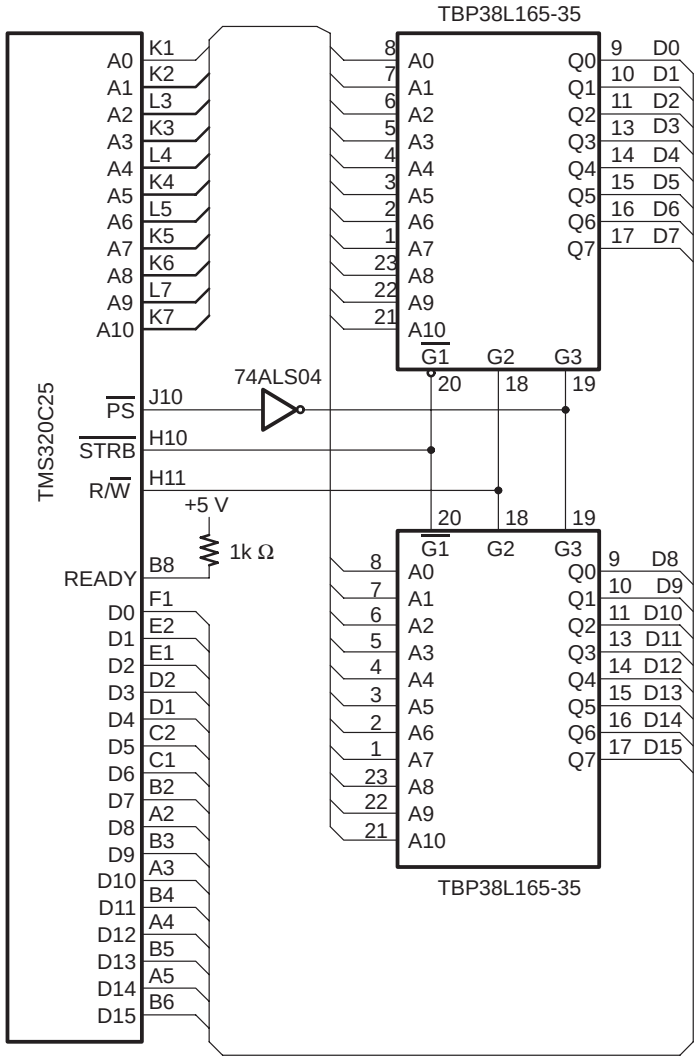
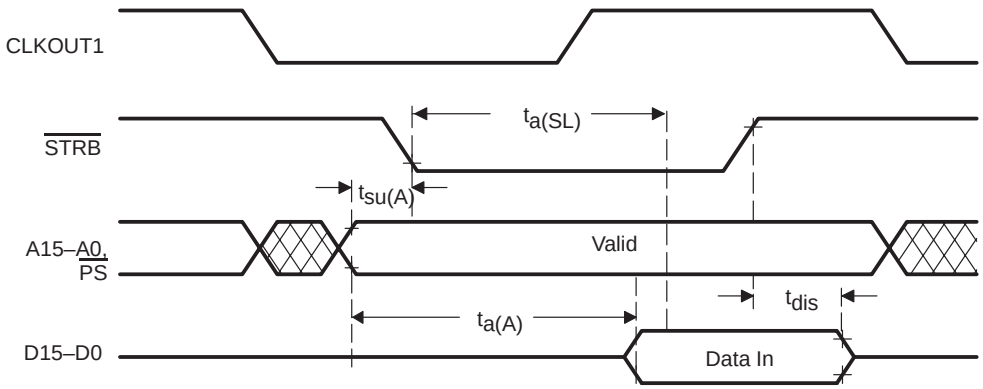


Figure 6–6. Interface Timing of TBP38L165-35 to TMS320C25



The most critical timing parameters of the TBP38L165 -35 direct interface to the TMS320C25 are summarized in Table 6–1.

Table 6–1. Timing Parameters of TBP38L165-35 Direct Interface to TMS320C25

Description	Symbol Used in Figure 6–6	Value
TMS320C25 address setup before strobe low	$t_{su(A)}$	13 ns (min)
TMS320C25 data setup time after strobe low	$t_{a(SL)}$	27 ns (max)
TMP38L165-35 disable time	t_{dis}	15 ns (max)
TMP38L165-35 access time from address	$t_{a(A)}$	35 ns (max)†
TMP38L165-35 access time from chip enable	$t_{a(S)}$	20 ns (max)
74ALS04 inverter rise time	t_{PLH}	11 ns (max)
Total address access time = $t_{a(A)} - t_{su(A)}$	$t_{a(A–SL)}$	22 ns (max)†
Total enable access time = $t_{a(S)} + t_{PLH} - t_{su(A)}$	$t_{a(E–SL)}$	18 ns (max)†

† Because $t_{a(E–SL)} < t_{a(A–SL)}$, the specification $t_{a(A)}$ dominates performance. All timing comparisons are made from strobe low.

The second design example illustrates the interface of PROMs to the TMS320C25 using address decoding. An approach that can be used to meet the READY timing requirements is shown in Figure 6–7. This design utilizes one address decoding scheme to generate READY, and a second address decoding scheme to enable the different memory banks. In this design, the memories with no wait states are mapped at the upper half (upper 32K) of the program space. The lower half is used for memories with one or more wait states. This decoding is implemented with the 74AS20 four-input NAND gate.

Address decoding is implemented by the 74AS138. This decoding separates the program space into eight segments of 8K words each. The first four of these segments (lower 32K of address space) are enabled by the Y0, $\overline{Y1}$, $\overline{Y2}$, and $\overline{Y3}$ outputs of the 74AS138. These segments are used for memories with one or more wait states. The other four segments select memories with no wait states (the TBP38L165s are mapped in segment 5, starting at address 8000h). Note that in Figure 6–7, R/$\overline{W}$ is used to enable the 74AS138. This prevents a bus conflict from occurring if an attempt is made to write to the PROMs. Figure 6–8 shows the timing for the circuit shown in Figure 6–7. READY goes high 10 ns (worst case) after the address has become valid.

Figure 6–7. Interface of TBP38L165-35 to TMS320C25

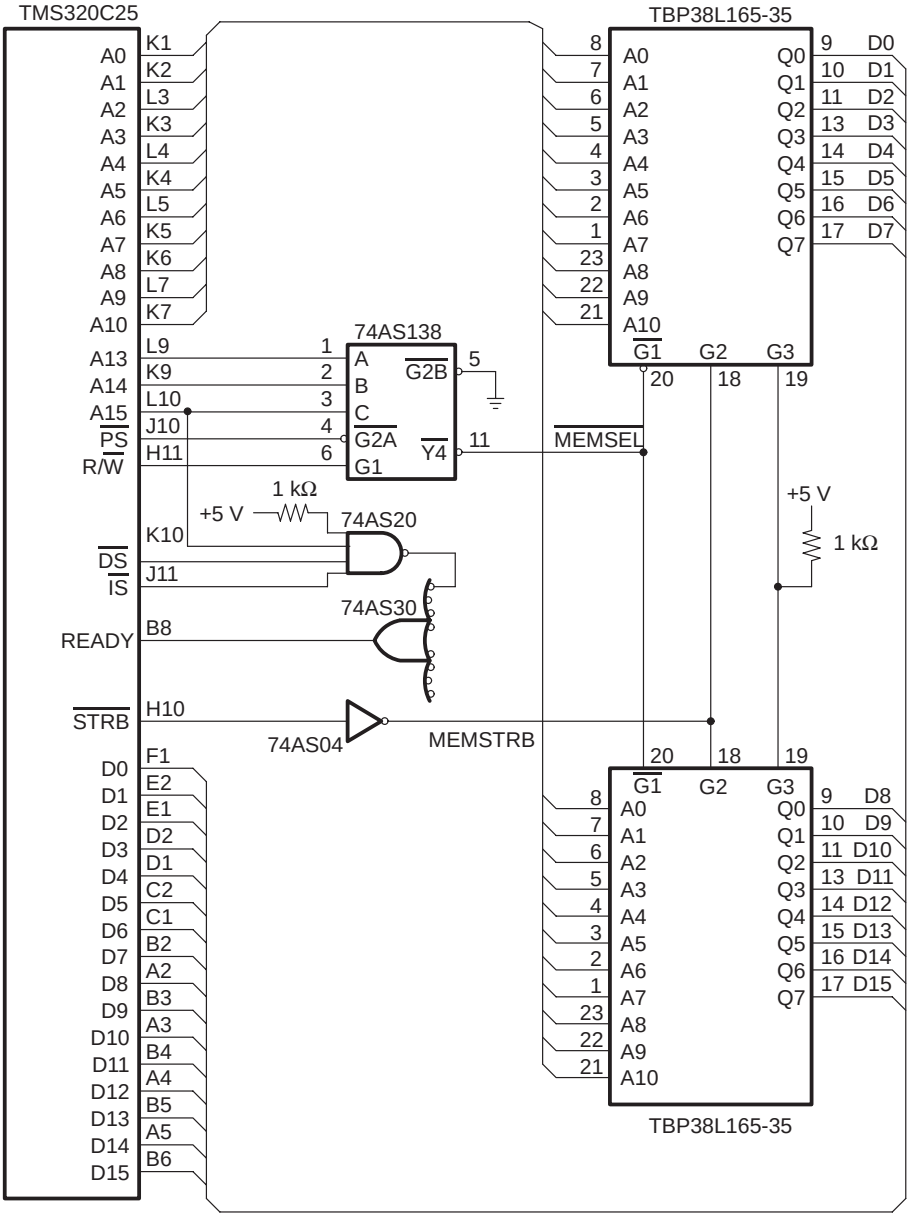
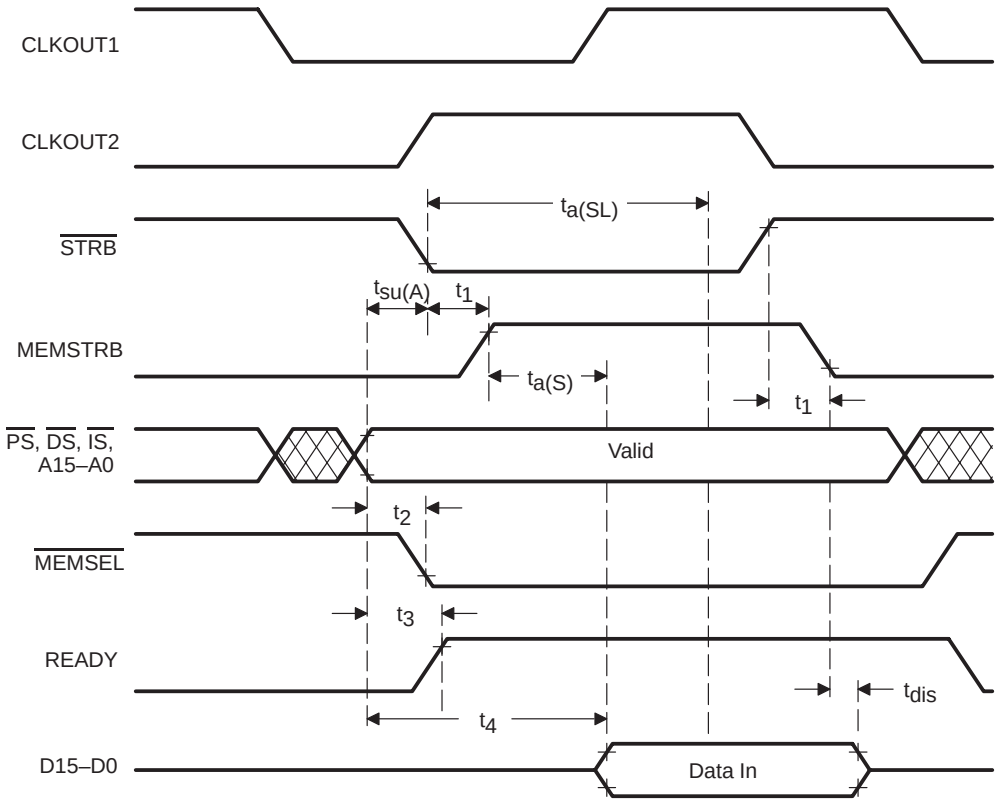


Figure 6–8. Interface Timing of TBP38L165-35 to TMS320C25 (Address Decoding)



The most critical timing parameters of the TBP38L165-35 interface with address decoding to the TMS320C25 are summarized in Table 6–2.

Table 6–2. Timing Parameters of TBP38L165-35 to TMS320C25 (Address Decoding)

Description	Symbol Used in Figure 6–8	Value
Propagation delay through the 74AS04	t_1	5 ns (max)
Propagation delay through the 74AS138	t_2	10 ns (max)
Address valid to READY	t_3	10 ns (max)
TBP38L165-35 disable time	t_{dis}	15 ns (max)
TBP38L165-35 address access time	t_4	35 ns (max)
TBPL165-35 enable access time	$t_{a(S)}$	20 ns (max)
Data latch setup time after strobe low	$t_{a(SL)}$	27 ns (max)

6.2.2 Wait-State Generator

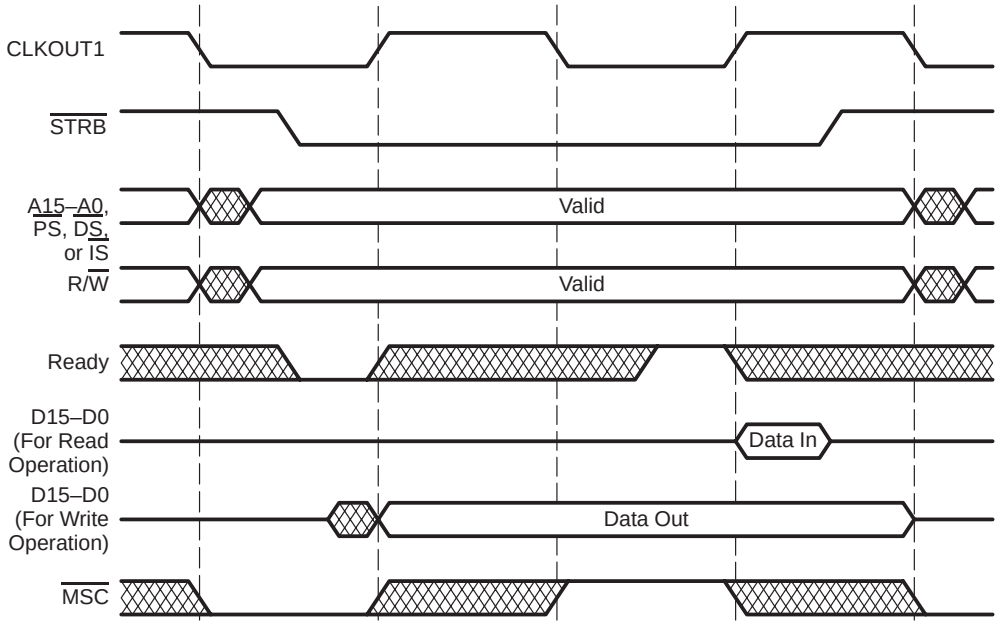
The READY input of the TMS320C2x allows it to interface with memory and peripherals that cannot be accessed in a single cycle. The number of cycles in a memory or I/O access is determined by the state of the READY input. If READY is high when the TMS320C2x samples the READY input, the memory access ends at the next falling edge of CLKOUT1. If READY is low, the memory cycle is extended by one machine cycle, and all other signals remain valid. Figure 6–9 shows a one-wait-state memory access. Note that for on-chip program and data memory accesses, the READY input is ignored. Refer to *Hardware Interfacing to the TMS320C25* for detailed information regarding wait-state generation.

You can automatically generate one wait state by using the microstate complete ($\overline{MSC}$) signal. The $\overline{MSC}$ output is asserted low during CLKOUT1 low to indicate the beginning of an internal or external memory or I/O operation (see Figure 6–9). By gating $\overline{MSC}$ with the address and $\overline{PS}$, $\overline{DS}$, and/or $\overline{IS}$, you can generate a one-wait state READY signal. Note that $\overline{MSC}$ is a valid signal only when CLKOUT1 is low; see page A–44.

A wait-state generator is an alternative approach for generating wait states when interfacing with memories and peripherals. In this design, READY must be valid (low or high) no later than Q–20 ns = 5 ns after $\overline{STRB}$ goes low. If READY is high, then the memory/peripheral access is completed with the present machine cycle. If READY is low, the access is extended to the next machine cycle; that is, a wait state is introduced. The number of wait states required depends on the access time t_a of the particular memory device or peripheral. If $t_a < 40$ ns, no wait states are required. If 40 ns $< t_a <$ 140 ns, one wait state must be inserted. In general, N wait states are required for a particular access if

TMS320C25: $[100 (N–1) + 40] \text{ ns} < t_a \leq [100N + 40] \text{ ns}$

Figure 6–9. One Wait-State Memory Access Timing



The information on the number of wait states required for a memory or peripheral access is summarized in Table 6–3.

Table 6–3. Wait States Required for Memory/Peripheral Access

Number Of Wait States Required	TMS320C25 Access Time
0	t_a < 40 ns
1	40 ns < t_a < 140 ns
2	140 ns < t_a < 240 ns
3	240 ns < t_a < 340 ns
4	340 ns < t_a < 440 ns

Design and timing of a wait-state generator are shown in Figure 6–10 and Figure 6–11, respectively. In the case of one wait state, time t_1 in Figure 6–11 is the time from address valid to memory select of the particular device that requires the wait state. This corresponds to the propagation delay through the address decode logic. For a 74AS138 decoder, t_1 = 10 ns (max).

Time t_2 is the time from memory select going low to CLKOUT2 going low.

$$t_2 = t_p + t_{su} = 11 \text{ ns} + 20 \text{ ns} = 31 \text{ ns}$$

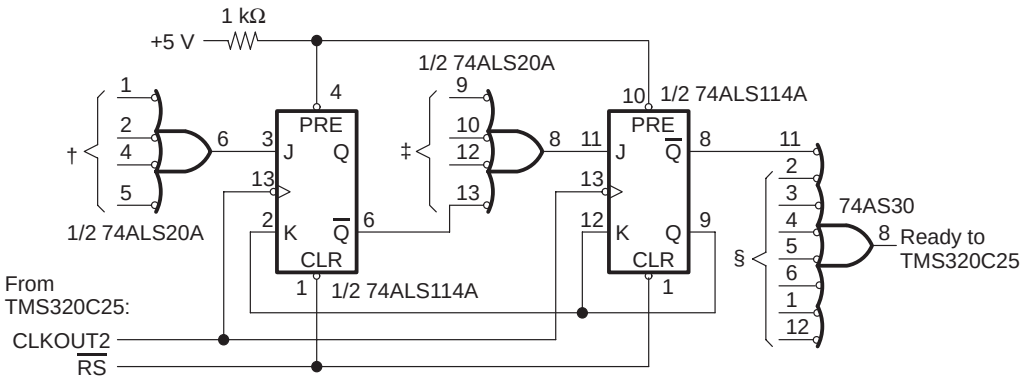
Time t_3 is the time from CLKOUT2 going low to READY going high.

$$t_3 = 19 \text{ ns} + 5 \text{ ns} = 24 \text{ ns}$$

READY must remain high until it is sampled again, shortly after CLKOUT1 goes high. In Figure 6–10, READY remains high well after CLKOUT1 goes high. On the falling edge of CLKOUT2, J = 1 and K = Q = 1 are the inputs to the J-K flip-flop; this places the flip-flop in a toggle mode. When CLKOUT2 goes low, $\overline{Q}$ goes back to logic 1. READY goes low and stays low until one of the inputs of the 74AS30 is pulled low.

To implement two wait states, a second J-K flip-flop is utilized as shown in Figure 6–10. This delays READY going high by an additional machine cycle (see Figure 6–11). If more wait states are required, additional J-K flip-flops must be included in the wait-state generator design.

Figure 6–10. Wait-State Generator Design

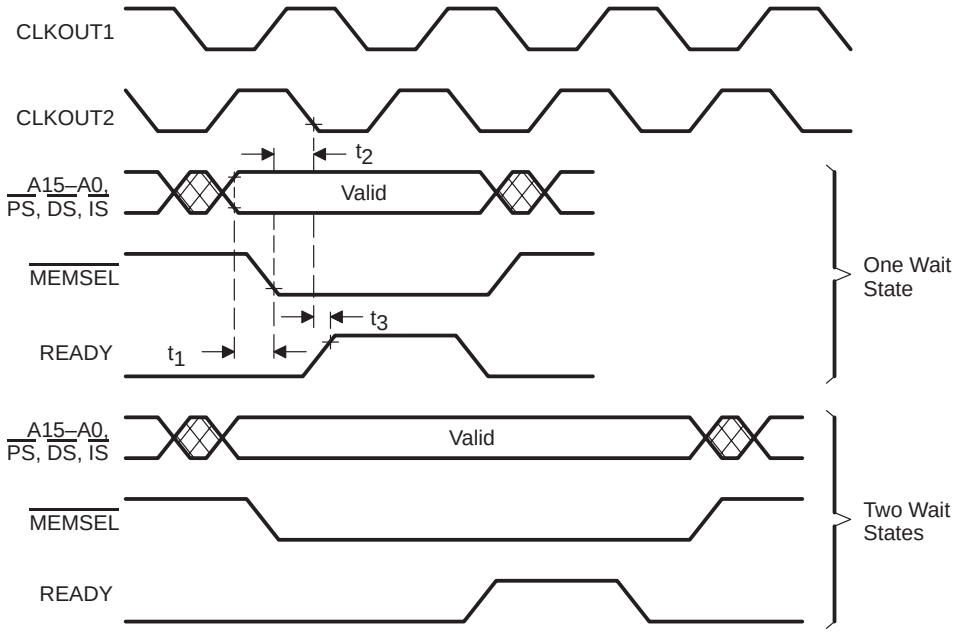


† Connections to other devices in the system that require two wait states. (Inputs not used by other devices should be pulled up.)

‡ Connections to other devices in the system that require one wait state. (Inputs not used by other devices should be pulled up.)

§ Connections to other devices in the system that require zero wait states. (Inputs not used by other devices should be pulled up.)

Figure 6–11. Wait-State Generator Timing



6.2.3 Interfacing EPROMs

EPROMs can be a valuable tool for debugging TMS320C2x algorithms during the prototyping stages of a design, and may even be desirable for production. Two different EPROM interfaces to the TMS320C2x are discussed: a direct interface of an EPROM that requires no wait states, and EPROM interfaces that require one and two wait states.

A direct interface similar to that used for PROMs may be implemented when EPROM access time meets the TMS320C2x timing specifications. A Texas Instruments TMS27C292-35 2K $\times$ 8-bit EPROM can interface directly to the TMS320C25 with no wait states. The TMS27C292-35 is a CMOS EPROM with access times of 35 ns from valid address and 25 ns from chip select.

When slower, less costly EPROMs are used, a simple flip-flop circuit (see subsection 6.2.2 for wait-state generator design) can be used to generate one or more wait states. Figure 6–12 shows an EPROM interface with one wait state, where Wafer Scale WS57C64F-12 8K $\times$ 8-bit EPROMs are interfaced to the TMS320C25. The WS57C64F-12 is the slowest member of the WS57C64F EPROM series but still meets the specifications for one wait state. With slower EPROMs, however, data output turnoff can be slow and must be taken into consideration in the design. The WS57C64F-12s are mapped at address 2000h. Figure 6–13 provides the interface timing diagram.

Figure 6–12. Interface of WS57C65F-12 to TMS320C25

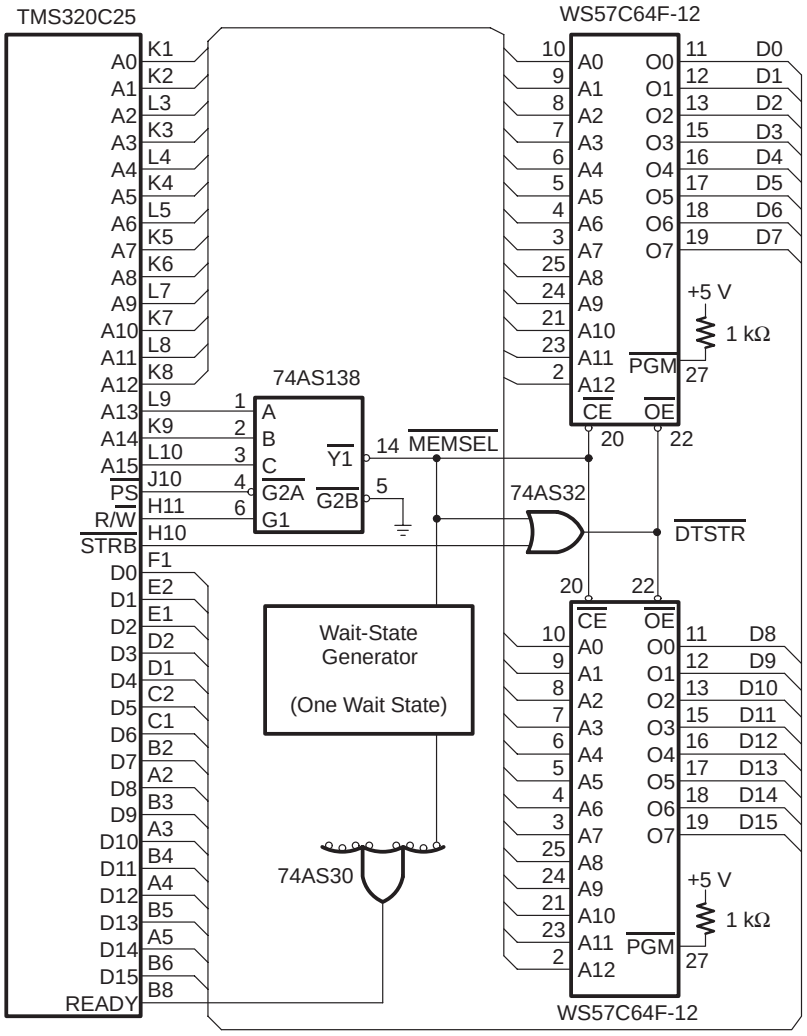


Figure 6–13. Interface Timing of WS57C65F-12 to TMS320C25

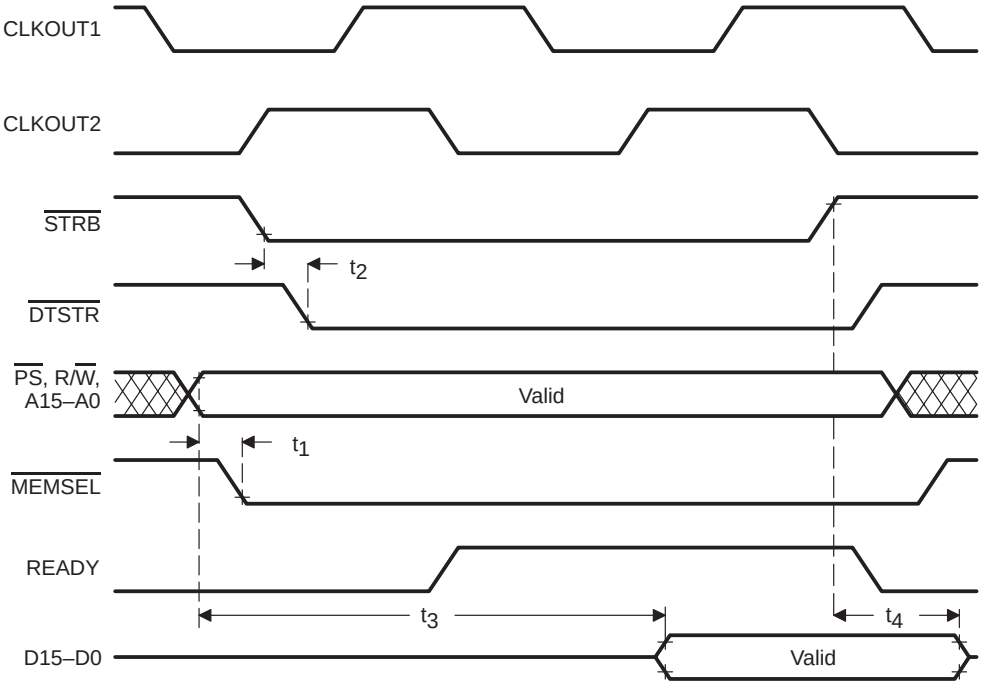


Table 6–4 summarizes the most critical timing parameters of the WS57C64F-12 interface to the TMS320C25.

Table 6–4. Timing Parameters of WS57C64F-12 Interface to TMS320C25

Description	Symbol Used in Figure 6–13	Value
Address valid to $\overline{\text{MEMSEL}}$ low	t_1	10 ns (max)
$\overline{\text{STRB}}$ low to $\overline{\text{DTSTR}}$ low)	t_2	5.8 ns (max)
TMS320C25 address valid to WS57C64F-12 data valid	t_3	130 ns (max)
$\overline{\text{STRB}}$ high to WS57C64F-12 output disable	t_4	40.8 ns (max)

An EPROM interface with two wait states is shown in Figure 6–14, in which the TMS27C64-20 is interfaced to the TMS320C25. The TMS27C64-20 is a CMOS 8K × 8-bit EPROM with an access time of 200 ns. The timing diagram is shown in Figure 6–15.

Figure 6–14. Interface of TMS27C64-20 to TMS320C25

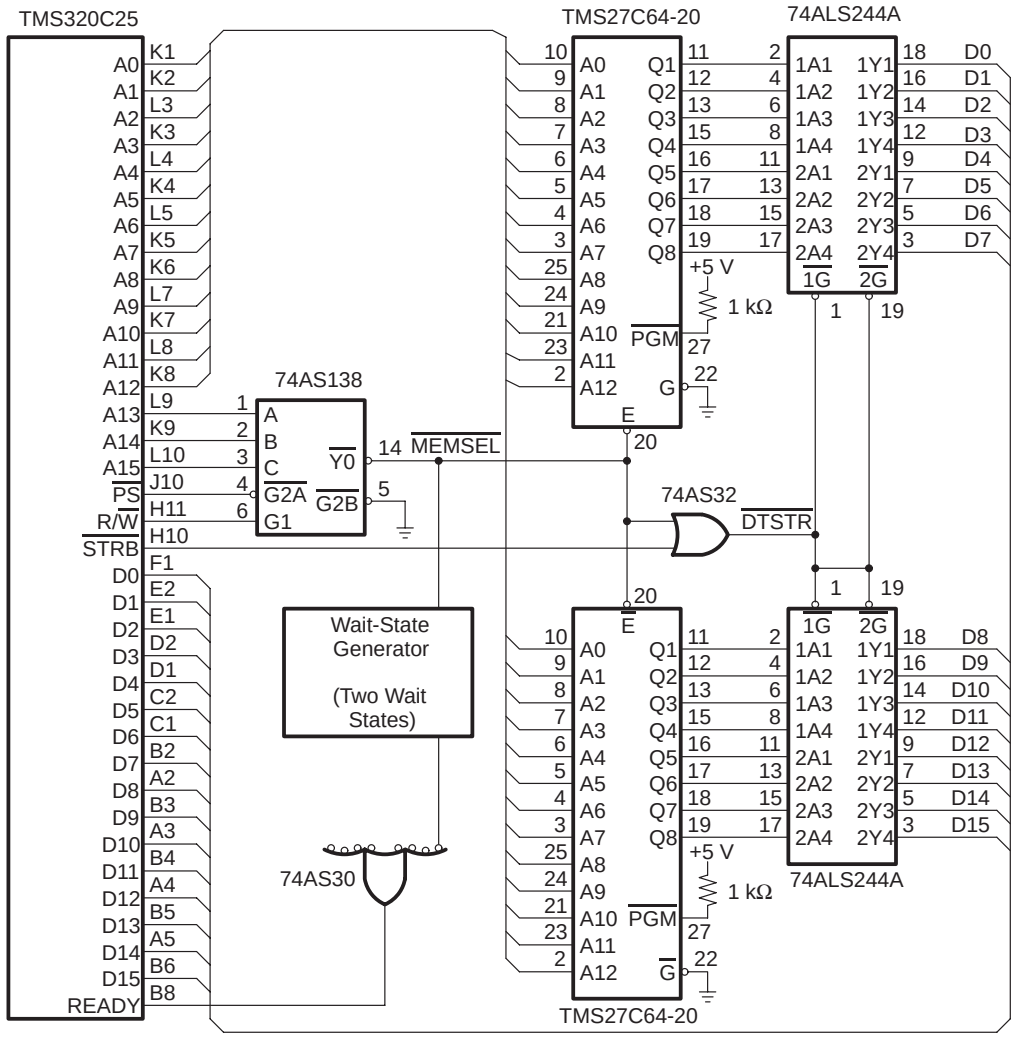


Figure 6–15. Interface Timing of TMS27C64-20 to TMS320C25

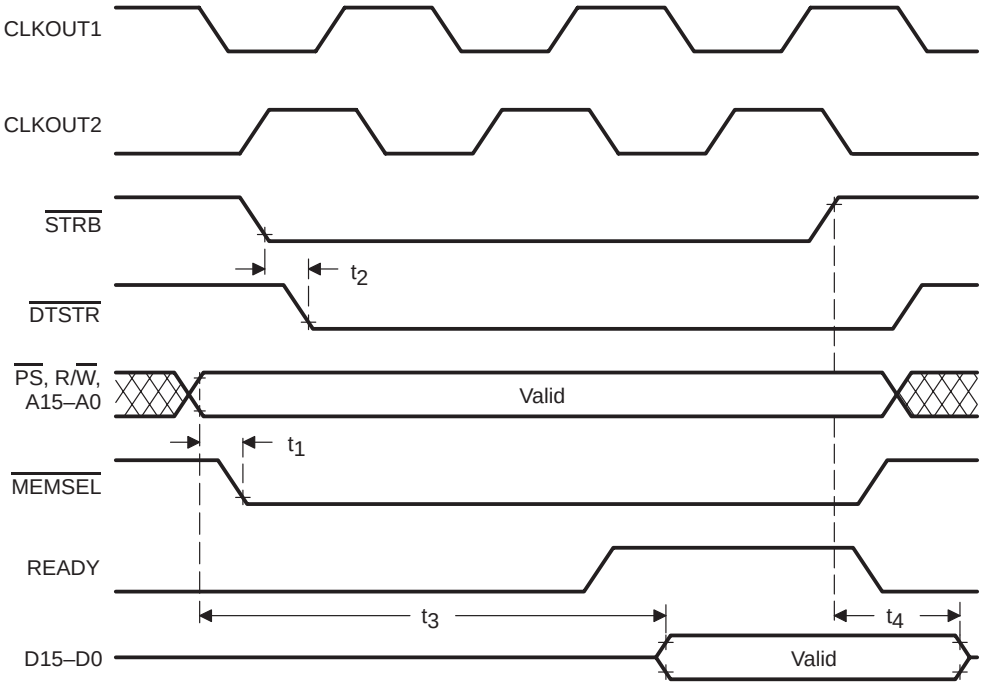


Table 6–5 summarizes the most critical timing parameters of the TMS27C64-20 interface to the TMS320C25.

Table 6–5. Timing Parameters of TMS27C64-20 Interface to TMS320C25

Description	Symbol Used In Figure 6–15	Value
Address valid to $\overline{\text{MEMSEL}}$ low	t_1	10 ns (max)
$\overline{\text{STRB}}$ low to $\overline{\text{DTSTR}}$ low	t_2	5.8 ns (max)
TMS320C25 address valid to TMS27C64-20 data valid	t_3	220 ns (max)
$\overline{\text{STRB}}$ high to TMS27C64-20 output disable	t_4	18.8 ns (max)

For detailed information regarding EPROM interfacing, see the application report, *Hardware Interfacing to the TMS320C25* (literature number SPRA014A).

6.2.4 Interfacing Static RAMs

Interfacing external RAM to the TMS320C2x can be useful for expanding internal data memory or implementing additional RAM program memory. Static RAM can be used as data memory to extend the TMS320C2x 544-word internal RAM. When used as program memory, object code can be downloaded into the RAM and executed. In the first case, the static RAM is mapped into the data space, while in the second case it is mapped into the program space.

In cases where RAMs of different speeds are used, separate schemes for address decoding and READY generation can be used to meet READY timing requirements in a manner similar to that used for the PROM interface described in subsection 6.2.1. RAMs with similar access times may then be grouped together in one segment of memory.

The static RAM for this interface is the Cypress Semiconductor CY7C169-25 4K × 4-bit static RAM. This RAM has a 25-ns access time from address $t_{a(A)}$ and a 15-ns access time from chip enable $t_{a(CE)}$. Note that these access times are fast enough so that a wait-state generator is not required for this interface. If, however, RAMs that require wait states are used in the system, the wait-state generator described in subsection 6.2.2 can be used.

The design shown in Figure 6–16 utilizes an approach similar to the one described in subsections 6.2.1 and 6.2.3; that is, one address decoding scheme is used to generate READY, and a second address decoding scheme enables the static RAM. In this design, RAMs with no wait states are mapped at the lower half (lower 32K words) of the TMS320C25 data space. The upper half is used for memories with one or more wait states. Figure 6–17 shows the timing for memory read and write cycles.

Table 6–6 summarizes the most critical timing parameters of the CY7C169-25 interface to the TMS320C25.

Table 6–6. Timing Parameters of CY7C169-25 Interface to TMS320C25

Description	Symbol Used In Figure 6–17	Value
Address valid to READY valid	t_1	10.8 ns (max)
$\overline{\text{STRB}}$ low to $\overline{\text{MEMSEL}}$ low	t_2	8.5 ns (max)
$\overline{\text{STRB}}$ high to $\overline{\text{MEMSEL}}$ high	t_3	7.5 ns (max)
CLKOUT1 low to TMS320C25 data bus entering the high-impedance state	t_4	15 ns (max)
$\overline{\text{MEMSEL}}$ low to CY7C169-25 driving the data bus	t_5	5 ns (min)
$\overline{\text{MEMSEL}}$ low to CY7C169-25 data valid	t_6	15 ns (max)
$\overline{\text{MEMSEL}}$ high to CY7C169-25 entering the high-impedance state	t_7	15 ns (max)
Data setup time for a write	t8	32 ns (min)
Data hold time	t9	7.5 ns (min)

Figure 6–16. Interface of CY7C169-25 to TMS320C25

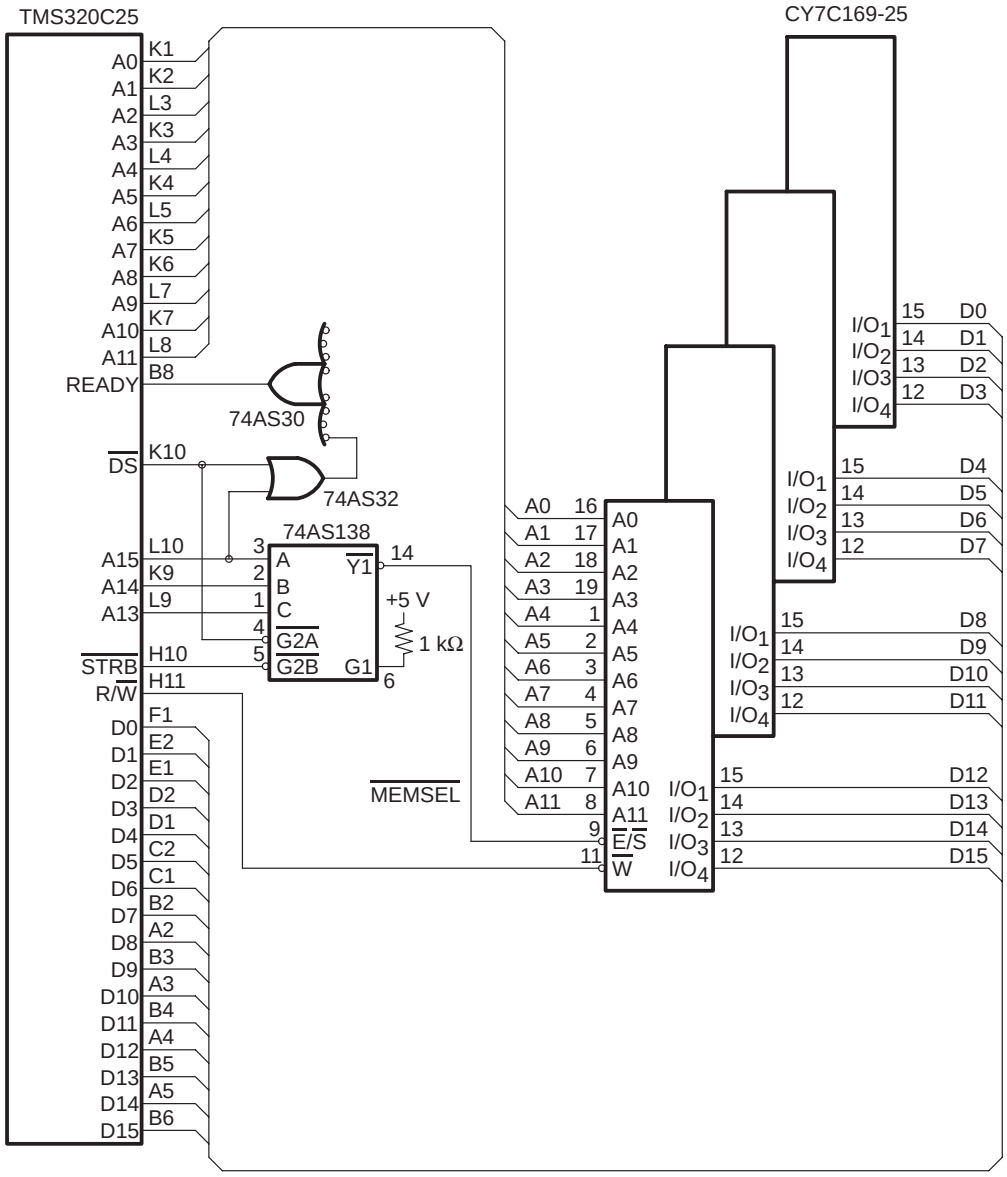
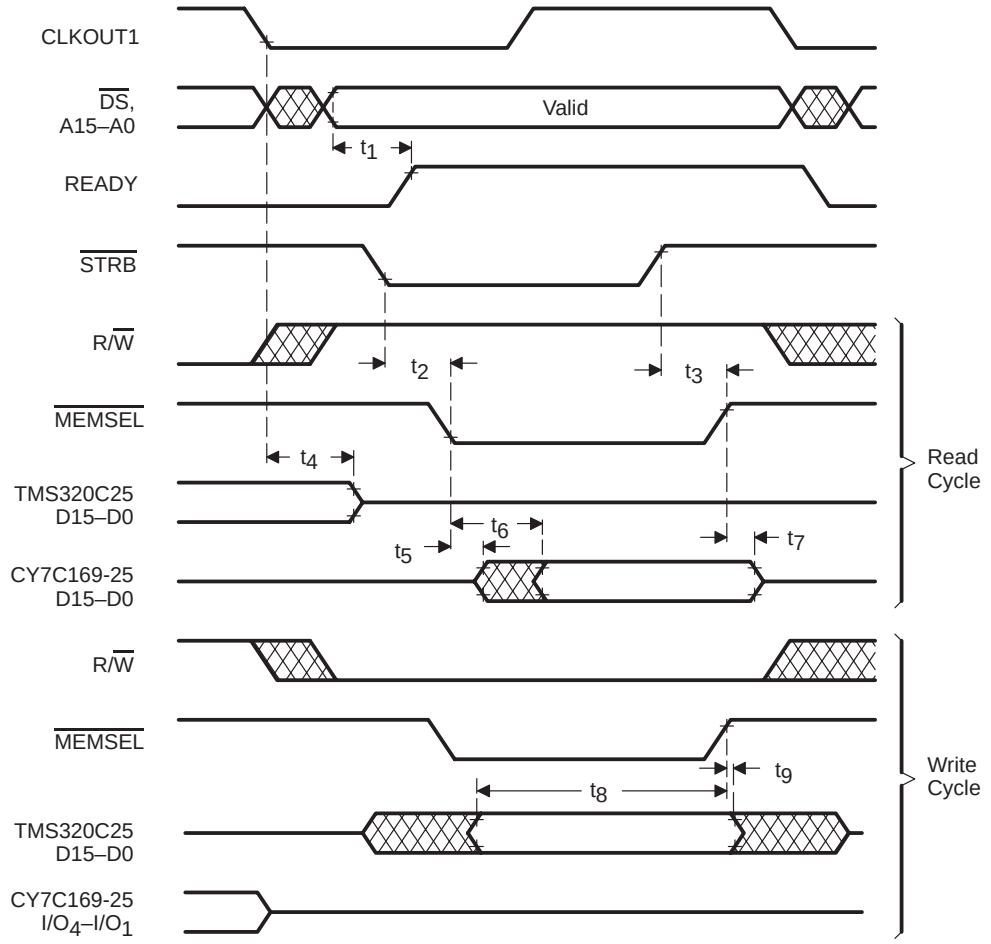


Figure 6–17. Interface Timing of CY7C169-25 to TMS320C25



6.2.5 Interface Timing Analysis

When interpreting TMS320C25 timing specifications, particularly in the area of memory interface timing, it is necessary to understand clock input and clock timing relationships shown in timing diagrams as compared with the actual data sheet specifications. If interpreted incorrectly, the specifications may suggest that interfacing to the device is more constrained than necessary. Without exception, the TMS320C25 meets every specification given in the data sheet (Appendix A). Some timings are specified more conservatively than others, due to yield distributions, etc.; but each TMS320C25 is guaranteed by Texas Instruments to conform explicitly with the minimum values as stated in the tables and shown in the timing diagrams of the data sheet.

Clock input and internal clock timing relationships must be considered in the interpretation of output timing characteristics and requirements. At the clock input to the device, only the rising edges of the clock are used to initiate transitions on internal clocks and output signals. Thus, with an input clock of a stable frequency (regardless of duty cycle variation within specifications), extremely symmetric timing is exhibited throughout the device. A significant consequence of this is that CLKOUT1, CLKOUT2, and $\overline{\text{STRB}}$ timing skew with respect to each other, and high and low pulse widths are integer multiples of Q (the input clock period or one-fourth of the output clock period) to within a few nanoseconds. This occurs because transitions on the output signals are initiated directly from the internal clocks (Q1–Q4) and driven through identical output buffer circuits. Since the internal clocks are very symmetric, close tracking of these outputs results. The large skews in these timings, as shown in the data sheet, are a factor of temperature and process. Because there is no variation in process and negligible variation in temperature across a single device, the skew of the outputs relative to the inputs is consistent for all outputs. Regardless of the magnitude of such skews, interfaces to the TMS320C25 can be designed independently of these skews in most cases.

This section discusses three interface timings: READY, memory read, and $\overline{\text{MSC}}$. For READY, there are two pairs of related timings; one timing can be met without the other one being met, and the device still guaranteed to function properly. These pairs of timings are $t_{d(SL–R)}$ and $t_{d(C2H–R)}$, and $t_{h(SL–R)}$ and $t_{h(C2H–R)}$. These front-end and back-end READY timings are specified with respect to $\overline{\text{STRB}}$ and CLKOUT2. For zero wait-state accesses, READY is referenced to STRB, but for wait-state accesses, $\overline{\text{STRB}}$ remains low and another timing reference is required. Note that the actual timings for each of these parameter pairs are identical, and the timings with respect to CLKOUT2 and $\overline{\text{STRB}}$ are equivalent. Therefore, if READY timing meets the requirements with respect to one of these references (but not necessarily the other), the timing requirements of the device are satisfied regardless of the actual skews between the two signals. For the purpose of interface timing, $t_{d(C2–S)}$ can be assumed to be 0 ns with respect to other signals on the TMS320C25. The same is also true of $t_{d(C1–S)}$ and $t_{w(SL)}$; these timings can be assumed to be Q and 2Q, respectively. These relationships are accounted for in specifications and device testing.

In memory read operations, the two key timings, $t_{a(A)}$ and $t_{su(D)R}$, are related by $t_{a(A)} = t_{su(A)} + t_{w(SL)} – t_{su(D)R}$. However, when the worst case $t_{w(SL)}$ specifications are used in this equation to generate an expression for $t_{a(A)}$, the result differs from the specification for $t_{a(A)}$ in the data sheet. Both the specification for $t_{a(A)}$ and $t_{su(D)R}$ are tested explicitly on the device and guaranteed. This again justifies the assumption of $t_{w(SL)}$ to be 2Q with respect to other signals on the device. This is confirmed by the fact that if $t_{w(SL)}$ = 2Q is used to calcu-

late $t_{a(A)}$, consistency results in all of these related timings. If an interface is designed where $t_{su(D)R}$ is met but $t_{a(A)}$ is not met because of actual signal skews, the interface is still guaranteed to function with the TMS320C25. The same is true (but is not as likely) if an interface is designed where $t_{a(A)}$ is met but $t_{su(D)R}$ is not. Thus, even if $t_{w(SL)}$ is actually less than 2Q, meeting either $t_{a(A)}$ or $t_{su(D)R}$ is still sufficent to guarantee a valid memory cycle because both parameters are guaranteed independently.

Note that when considered in the absolute sense, timings such as $t_{w(SL)}$ will have some finite tolerance, although considerably less than that specified. For example, if $\overline{\text{STRB}}$ is used to generate a $\overline{\text{WE}}$ pulse for a device that specifies a minimum $\overline{\text{WE}}$ low pulse width, the data sheet specification for $\overline{\text{STRB}}$ low pulse width must be used for a worst-case design.

When you design a multiwait-state generator and use the CLKOUT1 and CLKOUT2 signals for sequencing a state machine, specifications t_d(C2H–R) and t_h(C2H–R) must be met. Note that these signals are measured from CLKOUT2. If you design a single wait state, you can logically combine $\overline{\text{MSC}}$ with the address and memory strobes to generate $\overline{\text{READY}}$. In the latter, the parameters t_d(M–R) and t_h(M–R) must be met. In either case, both sets of parameters are tested and guaranteed.

Note that t_d(MSC) is also a parameter. As such, t_d(MSC) is given to locate $\overline{\text{MSC}}$ with respect to CLKOUT1 and CLKOUT2 for a multiwait-state design. In this case, it would be inappropriate to relate the $\overline{\text{READY}}$ timing requirements from the CLKOUT1 signal when considering a single wait state generated directly from $\overline{\text{MSC}}$.

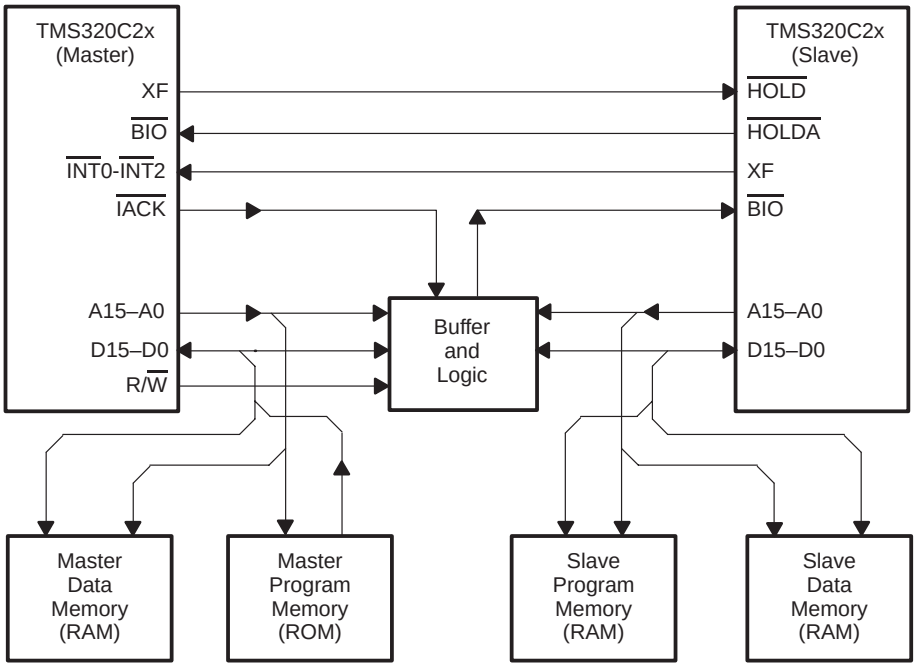
6.3 Direct Memory Access (DMA)

Some advanced hardware design concepts supported by the TMS320C2x include direct memory access (DMA) and global memory (see Section 6.4). Direct memory access can be used for multiprocessing by temporarily halting the execution of one or more processors to allow another processor to read from or write to the halted processor's local off-chip memory. Direct memory access to external program/data memory is performed by using the $\overline{\text{HOLD}}$ and $\overline{\text{HOLDA}}$ signals.

Multiprocessing is typically a master-slave configuration where the master may initialize a slave by downloading a program into its program memory space and/or by providing the slave with the necessary data to complete a task. In a typical TMS320C2x direct memory access scheme, the master may be a general-purpose CPU, another TMS320C2x, or perhaps even an analog-to-digital converter. A simple TMS320C2x master-slave configuration is shown in Figure 6–18. The master TMS320C2x takes complete control of the slave's external memory by asserting $\overline{\text{HOLD}}$ low via its external flag (XF). This causes the slave to place its address, data, and control lines in a high-impedance state. By asserting $\overline{\text{RS}}$ in conjunction with $\overline{\text{HOLD}}$, the master processor can load the slave's local program memory with the necessary initialization code on reset or powerup. The two processors can be synchronized by using the $\overline{\text{SYNC}}$ pin to make the transfer over the memory bus faster and more efficient.

After control of the slave's buses is given up to the master processor, the slave alerts the master to this fact by asserting $\overline{\text{HOLDA}}$. This signal may be tied to the master TMS320C2x's $\overline{\text{BIO}}$ pin. The slave's XF pin may be used to indicate to the master when it has finished performing its task and needs to be reprogrammed or requires additional data to continue processing. In a multiple slave configuration, priority of each slave's task may be determined by tying the slave's XF signals to the appropriate $\overline{\text{INT}}$(2–0) pin on the master TMS320C2x.

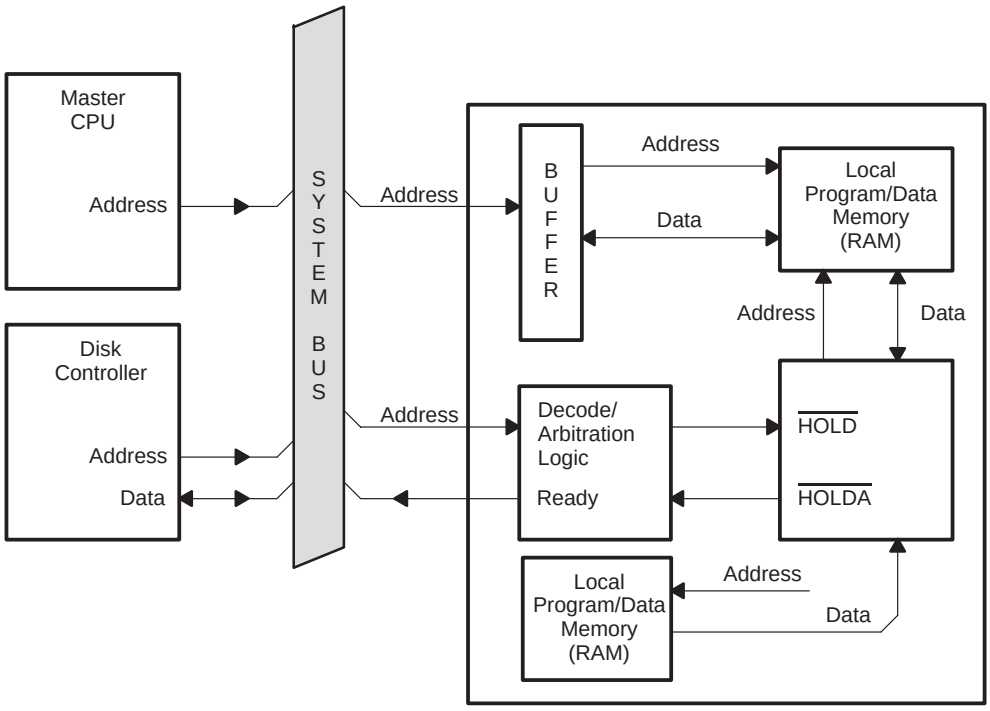
Figure 6–18. Direct Memory Access Using a Master-Slave Configuration



A PC environment presents another example of a potential direct memory access scheme in which a system bus (the PC bus) is used for data transfer. In this configuration, either the master CPU or a disk controller may place data onto the system bus, which can be downloaded into the local memory of the TMS320C2x. Here, the TMS320C2x acts more like a peripheral processor with multifunction capability. In a speech application, for example, the master can load the TMS320C2x's program memory with algorithms to perform such tasks as speech analysis, synthesis, or recognition, and fill the TMS320C2x's data memory with the required speech templates. In another application example, the TMS320C2x can serve as a dedicated graphics engine. Programs can be stored in TMS320C2x program ROM or downloaded via the system bus into program RAM. Data can come from PC disk storage or provided directly by the master CPU.

Figure 6–19 depicts a direct memory access using a PC environment. In this configuration, decode and arbitration logic is used to control the direct memory access. When the address on the system bus resides in the local memory of the peripheral TMS320C2x, this logic asserts the $\overline{\text{HOLD}}$ signal of the TMS320C2x while sending the master a not-ready indication to allow wait states. After the TMS320C2x acknowledges the direct memory access by asserting $\overline{\text{HOLDA}}$, READY is asserted and the information transferred.

Figure 6–19. Direct Memory Access in a PC Environment



6.4 Global Memory

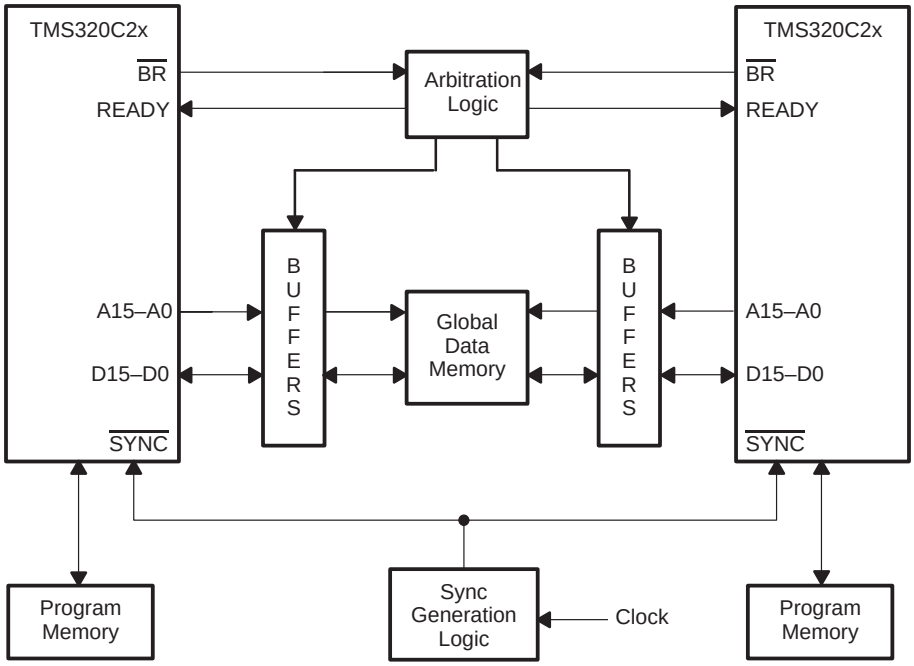
For multiprocessing applications, the external memory of the TMS320C2x can be divided into local and global sections. Special registers and pins included on the TMS320C2x allow multiple processors to share up to 32K words of global data memory space. This implementation facilitates efficient shared data multiprocessing in which data is transferred between two or more processors. Unlike a direct memory access (DMA) scheme, reading or writing global memory does not require one of the processors to be halted.

Global memory can be used in various digital signal processing tasks such as filters or modems, where the algorithm being implemented may be divided into sections with a distinct processor dedicated to each section. In this multiprocessor scheme, the first and second processors may share global data memory, as well as the second and third, the third and fourth, etc. Arbitration logic is required to determine which section of the algorithm is executing and which processor has access to the global memory. With multiple processors dedicated to distinct sections of the algorithm, throughput may be increased via pipelined execution.

By loading the global register (GREG), you can program the size of the global memory between 256 and 32K locations in data memory. After global memory is defined in the GREG, the TMS320C2x asserts the $\overline{BR}$ (bus request) signal before each global memory access. The $\overline{BR}$ signal stays low on back-to-back cycles in the TMS320C25. The processor then inserts wait states until a bus grant is given by asserting the READY line. Figure 6–20 illustrates such a global memory interface. Because the processors can be synchronized by using the $\overline{SYNC}$ pin, the arbitration logic can be simplified, and the address and data bus transfers can be more efficient (see subsection 3.10.1 for information on synchronization).

The $\overline{SYNC}$ pin on the TMS320C2x may also be used to synchronize several processors to allow for execution of redundant fail-safe systems. $\overline{SYNC}$ permits instruction broadcasting between several processors and lock-step execution after initial synchronization.

Figure 6–20. Global Memory Communication



6.5 Interfacing Peripherals

Most DSP systems implement some amount of I/O by using peripherals in addition to any memory included in the system. This usually includes analog input and output, which can be performed through the parallel and serial I/O ports on the TMS320C2x.

When you access the external parallel I/O ports, the access to the data bus is multiplexed over the same pins as for a program/data memory access. The I/O space is selected by the $\overline{IS}$ signal going active low, and the address of the port is placed on address bits A3–A0. Address bits A15–A4 are held low.

This section describes hardware interfaces to a TCM29C16 combo-codec, a TLC32040 analog interface circuit (AIC), a digital-to-analog (D/A) converter, and an analog-to-digital (A/D).

6.5.1 Combo-Codec Interface

Some areas of speech, telecommunications, and many other applications require low-cost analog-to-digital (A/D) and digital-to-analog (D/A) converters. Combo-codecs are most effective in serving DSP system data-conversion requirements. Combo-codecs are single-chip pulse-code-modulated encoders and decoders (PCM codecs), designed to perform the encoding (A/D conversion) and decoding (D/A conversion), as well as the antialiasing and smoothing filtering functions. Since combo-codecs perform these functions in a single 300-mil DIP package at low cost, they are extremely economical for providing system data-conversion functions.

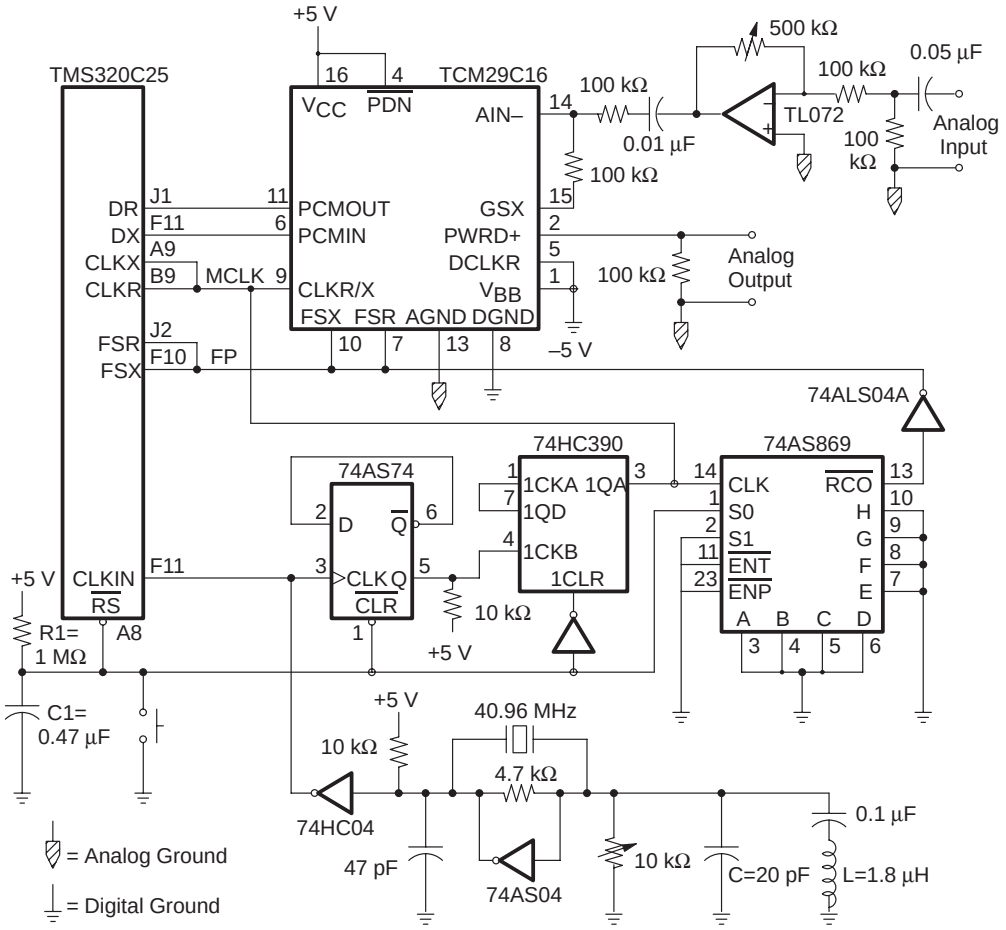
Combo-codecs interface directly to the TMS320C2x by means of the serial port and provide a companded, PCM-coded digital representation of analog input samples. This PCM code is easily translated into linear form by the TMS320C2x for use in processing. The design discussed here and shown in Figure 6–21 uses a Texas Instruments TCM29C16 codec, interfaced through using the serial port of the TMS320C25.

The TMS320C2x serial port provides direct synchronous communication with serial devices. The interface signals are compatible with codecs and other serial components so that minimal external hardware is required. Externally, the serial port interface is implemented via the following pins on the TMS320C25:

- DX (transmitted serial data)
- CLKX (transmit clock)
- FSX (transmit framing synchronization signal)
- DR (received serial data)
- CLKR (receive clock)
- FSR (receive framing synchronization signal)

Data on DX and DR are clocked by CLKX and CLKR, respectively. These clocks are required only during serial transfers on the TMS320C25. Note that the TMS320C25 is double-buffered.

Figure 6–21. Interface of TMS320C25 to TCM29C16 Codec



Serial port transfers are initiated by framing pulses on the FSX and FSR pins for transmit and receive operations, respectively. For transmit operations, the FSX pin can be configured as an input or an output. This option is selected by the transmit mode (TXM) bit of status register ST1. In this design, FSX is assumed to be configured as an input; therefore, transmit operations are initiated by a framing pulse on the FSX pin. Upon completion of receive and transmit operations, an RINT (serial port receive interrupt) and an XINT (serial port transmit interrupt) are generated, respectively. Interface timing of the TMS320C25 to the TCM29C16 corresponds to the burst-mode serial port transmit and receive operations shown in Figure 3–37 and Figure 3–38, respectively. Continuous-mode operation with or without framing pulses is also possible.

The format (FO) bit of status register ST1 is used to select the format (8-bit byte or 16-bit word) of the data to be received or transmitted. For interfacing the TMS320C25 to a codec, the format bit should be set to 1, formatting the data in 8-bit bytes.

The TMS320C25 interfaces directly to the codec, as shown in Figure 6–21, with no additional logic required. The PCM μ-law data generated by the codec at the PCMOUT pin is read by the TMS320C25 from the data receive (DR) pin, which is internally connected to the receive serial register (RSR). The data transmitted from the data transmit (DX) pin of the TMS320C25 is received by the PCMIN input of the codec. During the digital-to-analog conversion, this μ-law companded data must be converted back to a linear representation for use in the TMS320C25. The resulting analog waveform is lowpass-filtered by the codec's internal smoothing filter. Therefore, no additional filtering is required at the codec output (PWRO+). Software companding routines appropriate for use on the TMS320C25 are provided in the book, *Digital Signal Processing Applications with the TMS320 Family* (literature number SPRA012A).

The software required to initialize the TMS320C25-codec interface is provided in the combo-codec interface section of the application report, *Hardware Interfacing to the TMS320C25* (literature number SPRA014A). This report also presents detailed information regarding codec interfacing.

A combo-codec configured in the fixed-data-rate mode requires the following external clock signals:

- A 2.048-MHz clock to be used as the master clock, and
- 8-kHz framing pulses to initialize the data transfers.

Both of these signals can be derived from the 40.96-MHz system clock with appropriate divider circuitry. This is the primary justification for selecting 40.96 MHz as the system clock frequency. The clock divider circuit consists of a 74AS74 D-type flip-flop, a 74HC390 decade counter, and a 74AS869 8-bit up/down counter. The hardware connections between these devices are shown in Figure 6–21.

To generate the 2.048-MHz master clock for the combo-codec, a division by 20 of the 40.96-MHz system clock is required. The 74HC390 contains on-chip two divide-by-2 and two divide-by-5 counters. Because the 74HC390 cannot be clocked with frequencies above approximately 27 MHz, a 74AS74 configured as a divide-by-2 of the 40.96-MHz clock is used.

The 74AS869 is configured to generate the 8-kHz clock pulse (the ripple carry output is 2.048 MHz/256 = 8 kHz). This pulse is used by the TMS320C25 and codec as a framing pulse to initiate data transfers.

The level of the analog input signal is controlled by using the TL072 opamp connected in the inverting configuration (see Figure 6–21). Using the 500-kΩ potentiometer, the gain of this circuit can be varied from 0 to 5. The output of the 0.01-μF coupling capacitor drives the TCM29C16's internal opamp. This opamp is connected in the inverting configuration with unity gain (feedback and input impedances having the same value of 100 kΩ).

6.5.2 AIC Interface

For applications such as modems, speech, control, instrumentation, and analog interface for DSPs, a complete analog-to-digital (A/D) and digital-to-analog (D/A) input/output system on a single chip may be desired. The TLC32040 analog interface circuit (AIC) integrates on a single monolithic CMOS chip a bandpass, switched-capacitor, antialiasing-input filter, 14-bit resolution A/D and D/A converters, and a lowpass, switched-capacitor, output-reconstruction filter. The TLC32040 offers numerous combinations of master clock input frequencies and conversion/sampling rates, which can be changed via digital processor control.

Four serial port modes on the TLC32040 allow direct interface to TMS320C2x processors. When the transmit and receive sections of the AIC are operating synchronously, it can interface to two SN54299 or SN74299 serial-to-parallel shift registers. These shift registers can then interface in parallel to the TMS320C2x, to other TMS320 digital signal processors, or to external FIFO circuitry. Output data pulses are emitted to inform the processor that data transmission is complete or to allow the DSP to differentiate between two transmitted bytes. A flexible control scheme is provided so that the functions of the AIC can be selected and adjusted coincidentally with signal processing via software control. Refer to the TLC32040 data sheet for detailed information on timing and device functions.

The AIC is easily interfaced to the TMS320C2x serial ports, as shown in Figure 6–22. The TMS320C2x can communicate with the AIC either synchronously or asynchronously, depending on the information in the control register. The operating sequence for synchronous communication with the TMS320C2x, shown in Figure 6–23, is as follows:

1) The $\overline{\text{FSX}}$ or $\overline{\text{FSR}}$ pin is brought low.

2) One 16-bit word is transmitted, or one 16-bit word is received.

3) The $\overline{\text{FSX}}$ or $\overline{\text{FSR}}$ pin is brought high.

4) The $\overline{\text{EODX}}$ or $\overline{\text{EODR}}$ pin emits a low-going pulse.

For asynchronous communication, the operating sequence is similar, but $\overline{\text{FSX}}$ and $\overline{\text{FSR}}$ do not occur at the same time (see Figure 6–24). For proper operation, the TXM bit in the TMS320C2x control register should be set to 0 so that the FSX pin of the TMS320C2x is configured as an input, the format (FO) status bit is set to 0, and the AIC WORD/$\overline{\text{BYTE}}$ pin is at logic high. After each receive and transmit operation, the TMS320C2x asserts an internal receive (RINT) and transmit (XINT) interrupt, which may be used to control program execution.

Figure 6–22. Interface of TLC32040 to TMS320C2x

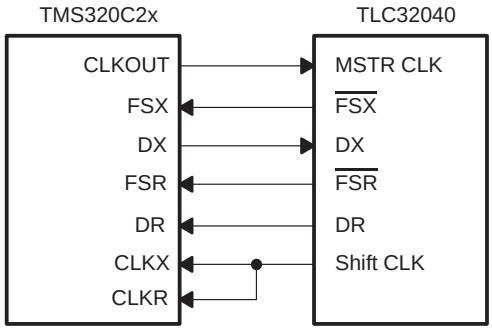


Figure 6–23. Synchronous Timing of TLC32040 to TMS320C2x

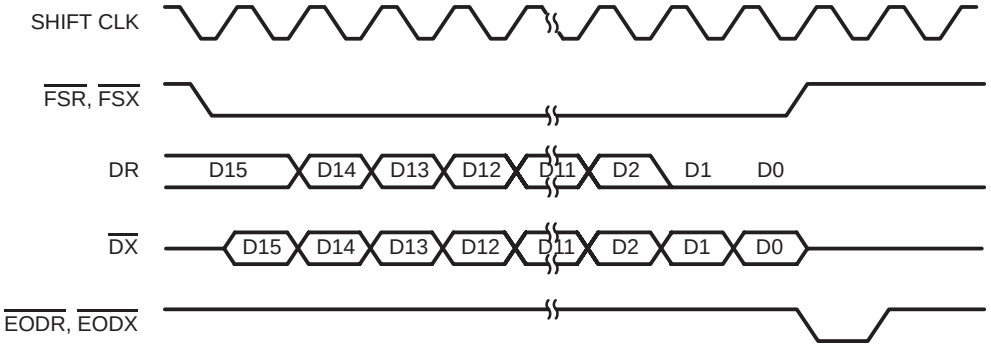
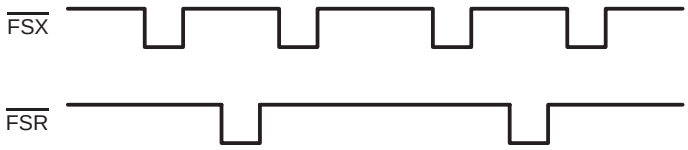


Figure 6–24. Asynchronous Timing of TLC32040 to TMS320C2x

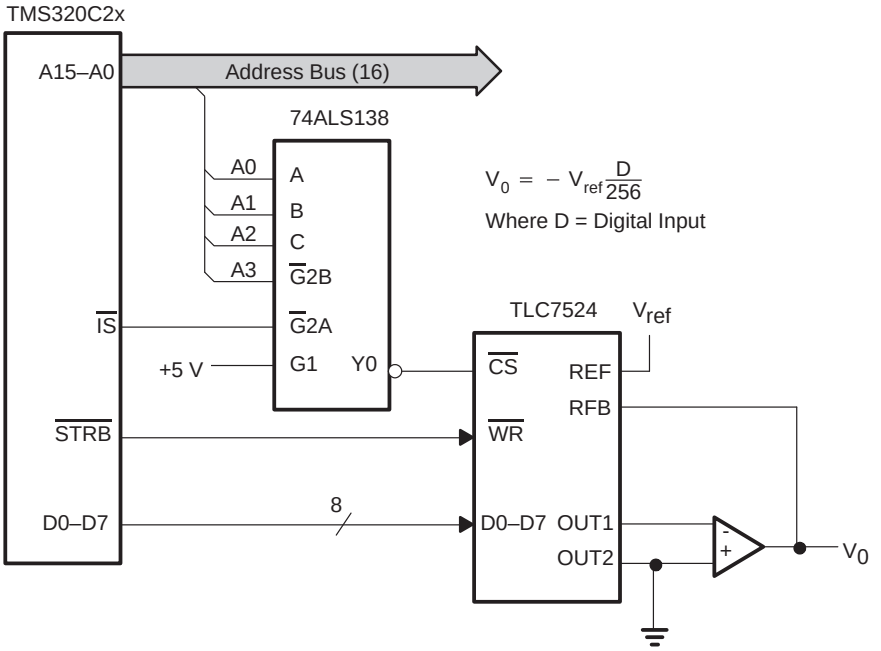


For further information regarding the AIC interface, see page 11–196 of *Linear and Interface Circuits Applications, Volume 3: Peripheral Drivers, Data Acquisition Systems, Hall-Effect Devices* (literature number SLYA003), published by Texas Instruments.

6.5.3 Digital-to-Analog (D/A) Interface

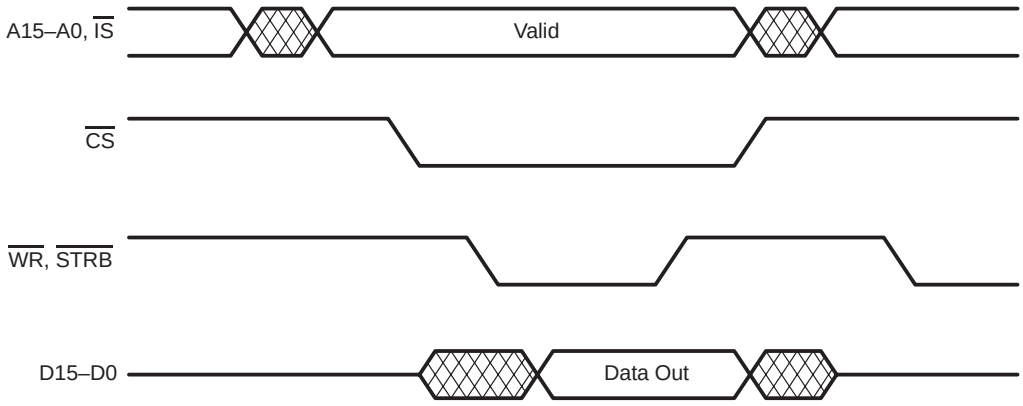
The high-speed operation of the internal logic circuitry of the TLC7524 8-bit digital-to-analog (D/A) converter allows an interface to the TMS320C2x with a minimum of external circuitry. Figure 6–25 shows the interface circuitry, which consists of one SN74ALS138 3-to-8-line decoder used to decode the address of the peripheral.

Figure 6–25. Interface of TLC7524 to TMS320C2x



When the TMS320C2x executes an OUT instruction (see Figure 6–28), the peripheral address is placed on the address bus and the $\overline{IS}$ line goes low, indicating that the address on the bus corresponds to an I/O port and not external data or program memory. A low level at $\overline{IS}$ enables the 74ALS138 decoder, and the Y-output, corresponding to the address on the bus, is brought low. When the Y-output is brought low, the TLC7524 is enabled and the data appearing on the data bus is latched into the D/A converter by $\overline{STRB}$. The controlling software for the D/A interface is given on page 11-204 of *Linear and Interface Circuits Applications, Volume 3: Peripheral Drivers, Data Acquisition Systems, Hall-Effect Devices* (literature number SLYA003), published by Texas Instruments.

Figure 6–26. Interface Timing of TLC7524 to TMS320C2x

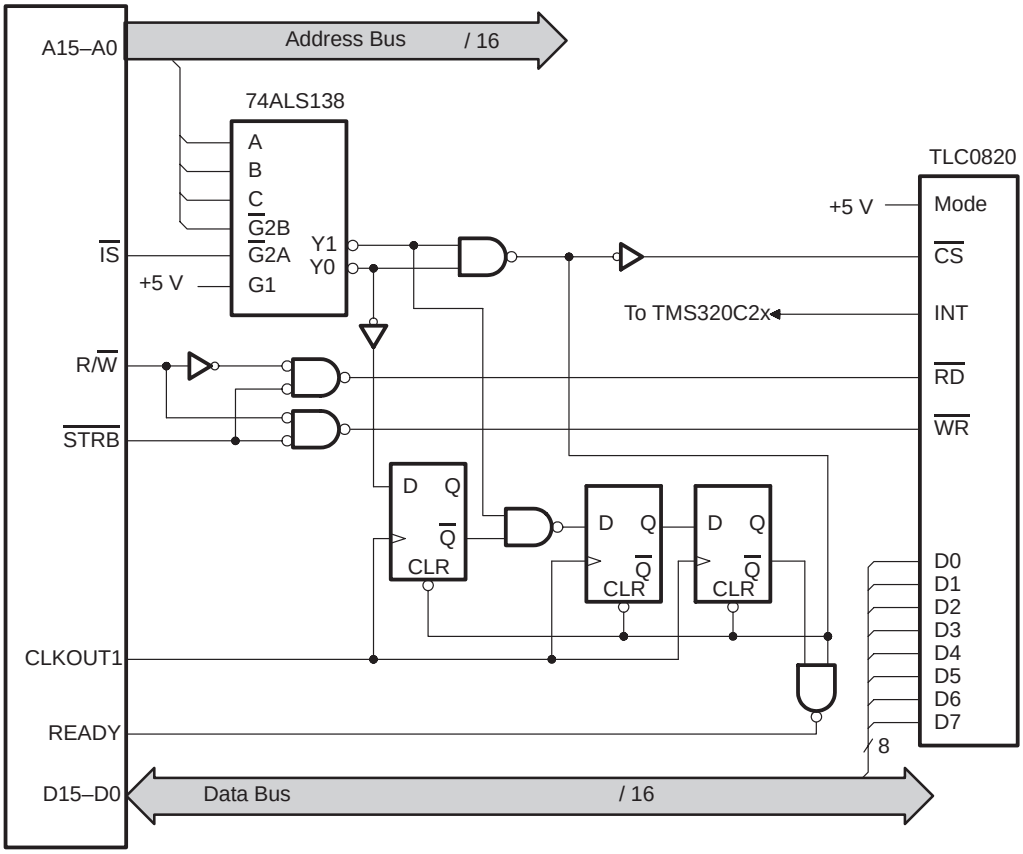


6.5.4 Analog-to-Digital (A/D) Interface

The TMS320C2x can be interfaced to 8-bit A/D converters, such as the TLC0820. However, because the control circuitry of the TLC0820 operates much more slowly than the TMS320C2x, it cannot be directly interfaced. In the TLC0820 to TMS320C2x interface design shown in Figure 6–27, the following logic devices are used in the interface circuit:

- A 3-line to 8-line decoder (SN74ALS138)
- A quad 2-input NAND gate (SN74LS00)
- A hex inverter (SN74LS04)
- A quad 2-input OR gate (SN74LS32)
- A quad D-type flip-flop (SN74LS175)

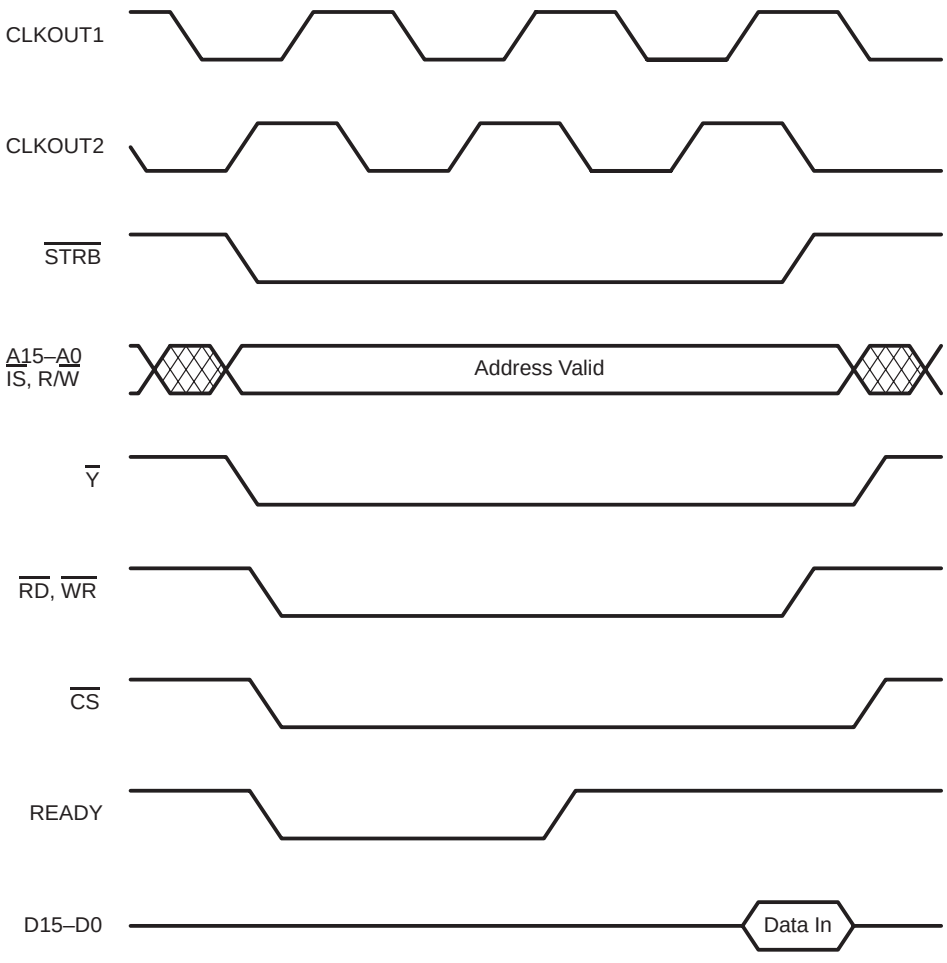
Figure 6–27. Interface of TLC0820 to TMS320C2x



The 74LS138 decodes the addresses assigned to the TLC0820. One of the addresses is used for a write operation; the other is used for a read operation. The two different addresses are necessary to ensure that the correct number of wait states is provided for the write and read operations. The controlling software for the A/D interface is given on page 11–206 of *Linear and Interface Circuits Applications, Volume 3: Peripheral Drivers, Data Acquisition Systems, Hall-Effect Devices* (literature number SLYA003), published by Texas Instruments.

With the TMS320C2x running at 20 MHz and the TLC0820 configured as slow memory, three wait states are necessary to provide a write pulse of sufficient length. After conversion has begun (with the rising edge of the $\overline{WR}$ signal), the TMS320C2x must wait at least 600 ns before the conversion result can be read. Sufficient delay should be provided in software. To read the conversion result, an adequate number of wait states must be provided to allow for the data access time (320 ns minimum) of the TLC0820. As shown in the IN instruction timing diagram of Figure 6–28, two wait states are provided when accessing port 1.

Figure 6–28. Interface Timing of TLC0820 to TMS320C2x

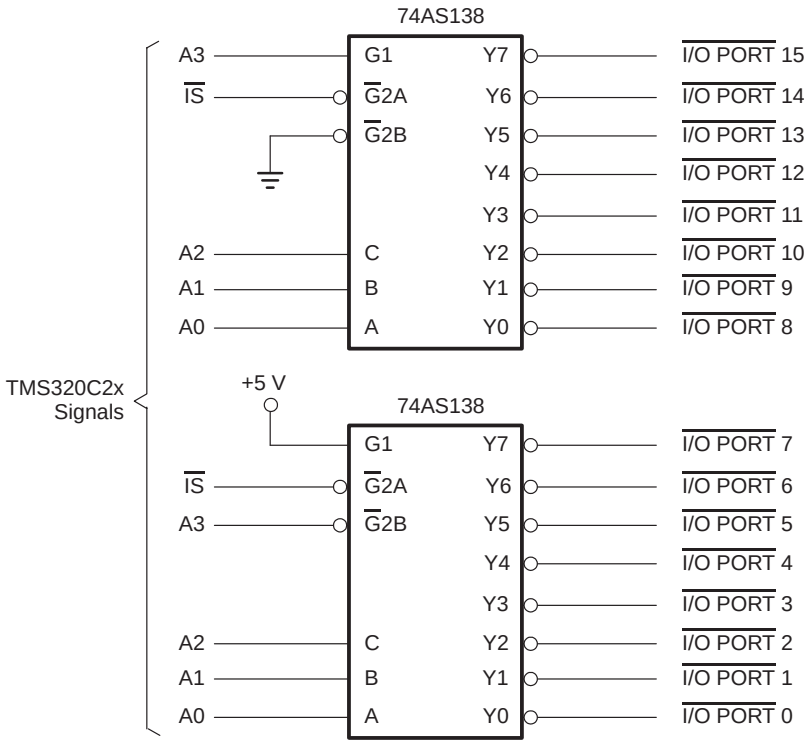


6.5.5 I/O Ports

I/O design on the TMS320C2x is treated the same way as memory. The I/O address space is distinguished from the local program/data memory space by the $\overline{IS}$ signal. $\overline{IS}$ goes low at the beginning of the memory cycle. All other control signals and timing parameters are the same as those for the program/data external memory interface.

The TMS320C2x software instructions can access 16 input and 16 output ports. The four least significant bits of the address bus specify the particular port being accessed. A pair of 74AS138s can be used to fully decode these address bits (see Figure 6–29).

Figure 6–29. I/O Port Addressing

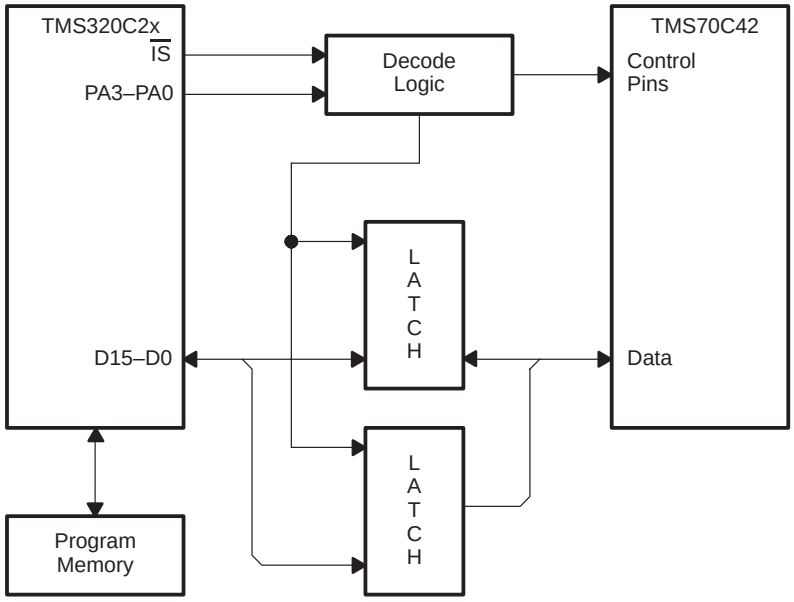


A simple interface between two processors can be implemented by using up to 16 bidirectional I/O ports connected to the TMS320C2x. An interprocessor communication path can be formed by memory-mapping peripherals to the I/O ports of the TMS320C2x. In this manner, the TMS320C2x can connect to parallel A/Ds, registers, FIFOs, two-port memories, or other peripheral devices. In a multiprocessing scheme, intelligent peripherals can be memory-mapped into the I/O ports. Here the TMS320C2x can communicate with UARTs, general-purpose microprocessors, disk controllers, video controllers, or other peripheral processors.

Using an 8-bit general-purpose microprocessor, such as TI's TMS70C42, for a keyboard interface is an example of a TMS320C2x I/O-port multiprocessing scheme, as shown in Figure 6–30. The TMS70C42 may be mapped into the TMS320C2x I/O space by using latches to store the transferred data. In a single or multiple I/O-port multiprocessing configuration, the four LSBs of the address bus are decoded to determine which of the 16 I/O ports on the TMS320C2x is being accessed. The TMS320C2x selects the I/O space ($\overline{IS}$) for its external bus and reads/writes data using the IN/OUT instructions.

Processor-controlled signals between the TMS320C2x and the peripheral device indicate when data is available to be read. This interprocessor communication is facilitated by using the input and output pins of the TMS70C42 (or other peripheral processor). In an I/O multiprocessing configuration, the I/O port address space is limited, and data transfers are relatively slow compared to a direct memory access or global memory configuration.

Figure 6–30. I/O Port Processor-to-Processor Communication



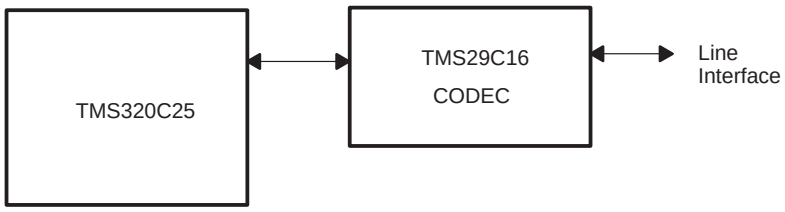
6.6 System Applications

The TMS320C2x is used in a wide variety of systems. Several applications in the areas of telecommunications, graphics and image processing, high-speed control, instrumentation, and numeric processing are described in the following paragraphs to illustrate basic approaches to system design with the TMS320C2x.

6.6.1 Echo Cancellation

Digital signal processing is extensively used in telecommunications applications. In echo cancellation, an adaptive FIR filter performs the modeling routine and signal modifications required to adaptively cancel the echo caused by impedance mismatches in telephone transmission lines. The TMS320C25's large on-chip RAM of 544 words and on-chip ROM of 4K words allow it to execute a 256-tap adaptive filter (32-ms echo cancellation) without external data or program memory. Figure 6–31 shows a common configuration for an echo canceller that uses a TCM29C16 codec interface.

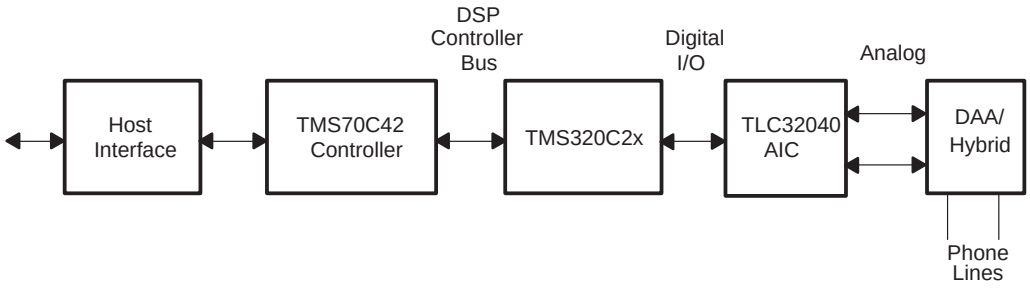
Figure 6–31. Echo Canceler



6.6.2 High-Speed Modem

In high-speed modems, a signal processor performs functions such as modulation/demodulation, adaptive equalization, and echo cancellation. The TMS320C2x large memory space allows it to support multiple standards such as Bell 103, Bell 212A, V.22 bis, V.29, V.32, and V.33, as well as proprietary algorithms. The modem shown in Figure 6–32 consists of the host interface, controller, DSP, and analog front-end.

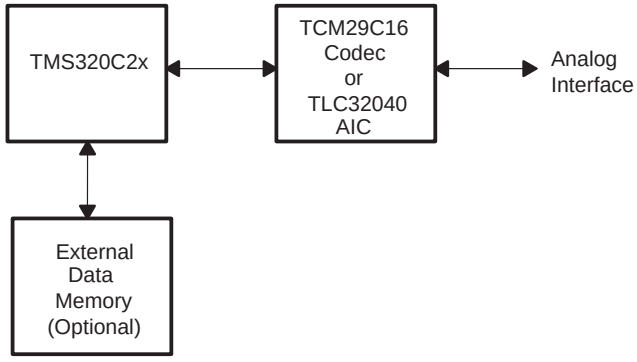
Figure 6–32. High-Speed Modem



6.6.3 Voice Coding

Voice coding techniques, such as full-duplex 32-kbps adaptive differential pulse-code modulation (CCITT G.721), 16-kbps sub-band coding, and linear predictive coding, are frequently used in voice transmission and storage. The speed of the TMS320C2x in performing arithmetic computations, normalization, and bit manipulation enables it to implement these functions usually internally (that is, with no external devices). Figure 6–33 shows a voice coding system consisting of a TMS320C2x DSP, TCM29C16 codec or TLC32040 AIC, and optional external memory.

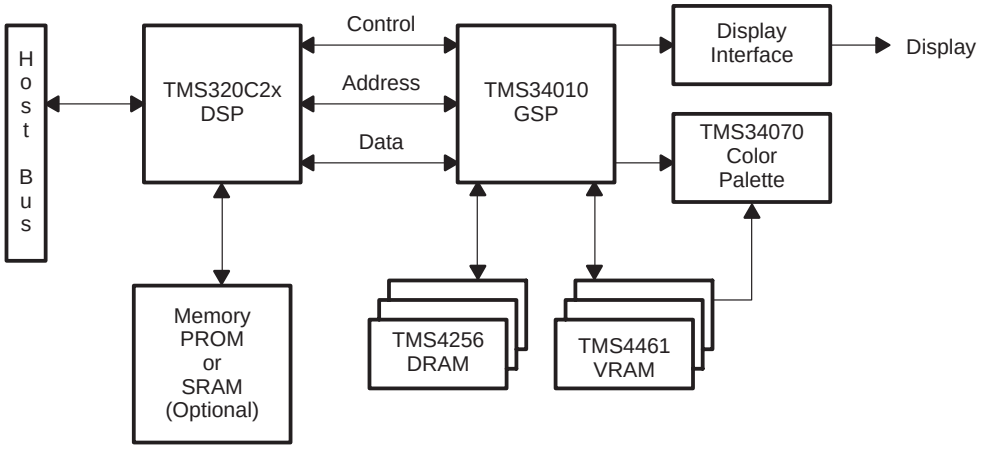
Figure 6–33. Voice Coding System



6.6.4 Graphics and Image Processing

In graphics and image processing applications, a signal processor's ability to interface with a host processor is important. The TMS320C2x multiprocessor interface enables it to be used in a variety of host/coprocessor configurations (see Figure 6–34 for an example of a graphics system configuration). Graphics and image processing applications can use the large, directly addressable external data memory space and global memory capability to share graphical images in memory with a host processor, thus minimizing data transfers. Indexed indirect addressing modes on the TMS320C2x allow matrices to be processed row by row when matrix multiplication is performed for 3-D image rotation, translation, and scaling.

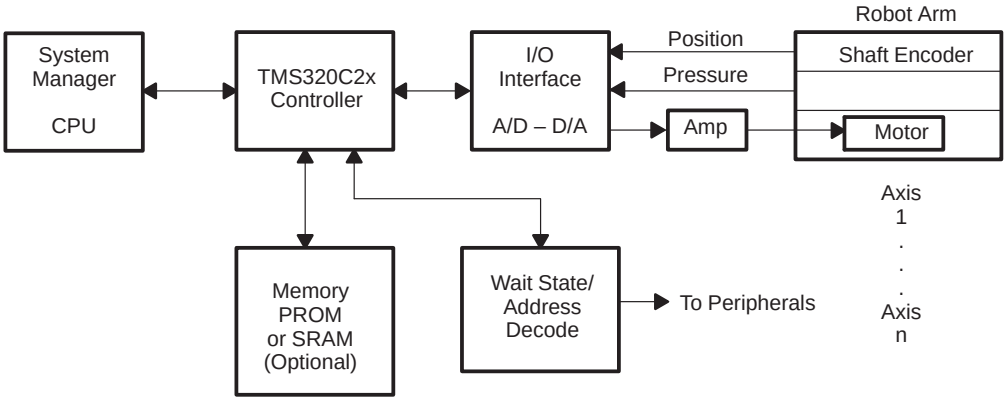
Figure 6–34. Graphics System



6.6.5 High-Speed Control

High-speed control applications, such as robotics, use the TMS320C2x general-purpose features for bit manipulation, logical operations, timing synchronization, and fast data transfers (10 million 16-bit words per second). In addition to the numeric-intensive control functions typical of robotic applications, the TMS320C2x provides a host interface whereby a robot can communicate to a central host processor (see Figure 6–35). The TMS320C2x is also used in the closed-loop systems of disk drives for signal conditioning, filtering, high-speed computing, and multichannel multiplexing.

Figure 6–35. Robot Axis Controller Subsystem



6.6.6 Instrumentation and Numeric Processing

Instrumentation, such as spectrum analyzers, requires a large data memory space and a processor, such as the TMS320C2x, that is capable of performing long-length FFTs and generating high-precision functions with minimal external hardware. Figure 6–36 shows an example of an instrumentation system. Numeric processing applications benefit from the high throughput, multiprocessing, and data memory expansion capabilities of the TMS320C2x.

Figure 6–36. Instrumentation System

Appendix A

TMS320C25 and TMS320E25 Digital Signal Processors

This appendix contains data sheet information on the TMS320C25 digital signal processors family, which includes the following devices:

- TMS320C25
- TMS320C25-33
- TMS320C25-50
- TMS320E25

Refer to Appendix B for data sheet information on the TMS320C26, to Appendix C for the TMS320C28, and to Appendix D for the military versions.

Appendix B

TMS320C26 Digital Signal Processor

This appendix contains data sheet information on the TMS320C26 digital signal processor.

Appendix C

TMS320C28 Digital Signal Processor

This appendix contains data sheet information on the TMS320C28 digital signal processor.

Appendix D

Instruction Cycle Timings

This appendix details the instruction cycle timings for the TMS320C2x processor. Instructions are first listed in a table according to cycle classification. Then each class of instructions is listed in another table, showing the number of cycles required for a TMS320C2x instruction to execute in a given memory configuration singly or in repeat mode. The column headings in the tables indicate the program source location (PI, PE, or PR) and data destination or source (DI or DE), defined as follows:

PI The instruction executes from internal program memory (RAM).
PR The instruction executes from internal program memory (ROM).
PE The instruction executes from external program memory.
DI The instruction executes using internal data memory.
DE The instruction executes using external data memory.

The number of cycles required for each instruction is given in terms of the program/data memory and I/O access times as defined in the following listing:

p Program memory wait states. Represents the number of clock cycles the device waits for external program memory to respond to an access. T_{ac} is the TMS320C2x access time, in nanoseconds (maximum), required for an external memory access with no wait states. T_{mem} is the memory access time, and T_p is the clock period (4/crystal frequency).
$p = 0$; If $T_{mem} \leq T_{ac}$
$p = 1$; If $T_{ac} < T_{mem} \leq (T_p + T_{ac})$
$p = 2$; If $(T_p + T_{ac}) < T_{mem} \leq (T_p \times 2 + T_{ac})$
$p = k$; If $[T_p \times (k - 1) + T_{ac}] < T_{mem} \leq (T_p \times k + T_{ac})$

d Data memory wait states. Represents the number of cycles the device must wait for external data memory to respond to an access. This number is calculated in the same way as the p number.

i I/O memory wait states. Represents the number of cycles the device must wait for external I/O memory to respond to an access. This number is calculated in the same way as the p number.

Other abbreviations used in the tables and their meanings are as follows:

br Branch from ...
int Internal program memory.
INT Interrupt.
ext External program memory.
n The number of times an instruction is executed when using the RPT or RPTK instruction.

D.1 TMS320C2x Instruction Cycle Timings

Table D–1 lists the TMS320C2x instructions according to cycle classification. Table D–2 and Table D–3 show the number of cycles required for a given TMS320C2x instruction to execute in a given memory configuration when executed as a single instruction or in the repeat mode, respectively.

Table D–1. TMS320C2x Instructions by Cycle Class

CLASS	INSTRUCTION
I	ADD ADDC ADDH ADDS ADDT AND BIT BITT DMOV LAC LACT LPH LT LTA LTD LTP LTS MPY MPYA MPYS MPYU PSHD OR RPT SQRA SQRS SUB SUBB SUBC SUBH SUBS SUBT XOR ZALH ZALR ZALS (RPT not repeatable)
II	LAR LDP LST LST1
III	POPD SACH SACL SAR SPH SPL SST SST1
IV	ABS ADDK ADRK APAC CMPL CMPR CNFD CNFP DINT EINT FORT LACK LARK LARP LDPK MAR MPYK NEG NOP NORM PAC POP PUSH RC RFSM RHM ROL ROR ROVM RPTK RSXM RTC RTXM RXF SBRK SC SFL SFR SFSM SHM SOVM SPAC SPM SSXM STC STXM SUBK SXF ZAC (ADDK, ADRK, LACK, LARK, LDPK, MPYK, RPTK, SBRK, SPM, SUBK, and ZAC not repeatable)
V	ADLK ANDK LALK LRLK ORK SBLK XORK (all not repeatable)
VI	MAC MACD
VI	B BANZ BBNZ BBZ BC BGEZ BGZ BIOZ BLEZ BLZ BNC BNV BNZ BV BZ CALL (all not repeatable)
VIII	BACC CALA RET TRAP (all not repeatable)
IX	IN
X	OUT
XI	TBLR
XII	TBLW (table in ROM not applicable)
XIII	BLKD
XIV	BLKP
XV	IDLE (not repeatable)

Table D–2. Cycle Timings for Cycle Classes When Not in Repeat Mode

CLASS	PI/DI	PI/DE	PE/DI	PE/DE	PR/DI	PR/DE
I	1	2+d	1+p	2+d+p	1	2+d
II	1	2+d	1+p	2+d+p	1	2+d
III	1	1+d	1+p	2+d+p	1	1+d
IV	1	1	1+p	1+p	1	1
V	2	2	2+2p	2+2p	2	2
VI	Table in on-chip RAM:					
	3	4+d	4+2p	5+d+2p	4	5+d
	Table in on-chip ROM:					
	4	5+d	4+2p	5+d+2p	4	5+d
	Table in external memory:					
	4+p	5+d+p	4+3p	5+d+3p	4+p	5+d+p
VII	True Conditions:					
	Destination on-chip RAM:					
	2	2	2+2p	2+2p	2	2
	Destination on-chip ROM:					
	3	3	3+2p	3+2p	3	3
	Destination external memory:					
	3+p	3+p	3+3p	3+3p	3+p	3+p
	False Condition:					
	Destination anywhere:					
	2	2	2+2p	2+2p	2	2
VIII	Destination on-chip RAM:					
	2	2	2+p	2+p	2	2
	Destination on-chip ROM:					
	3	3	3+p	3+p	3	3
	Destination external memory:					
	3+p	3+p	3+2p	3+2p	3+p	3+p
IX	2+i	2+d+i	2+p+i	3+d+p+i	2+ i	2+d+i
X	1+i	2+d+i	2+p+i	3+d+p+i	1+i	2+d+i
XI	Table in on-chip RAM:					
	2	2+ d	3+p	3+d+p	3	3+d
	Table in on-chip ROM:					
	3	3+d	4+p	4+d+p	4	4+d
	Table in external memory:					
	3+p	3+d+p	4+2p	4+d+2p	4+p	4+d+p
XII	Table in on-chip RAM:					
	2	3+d	3+p	4+d+p	3	4+d
	Table in on-chip ROM:					
	not applicable					
	Table in external memory:					
	2+p	3+d+p	3+2p	4+d+2p	3+p	4+d+p

Table D–2. Cycle Timings for Cycle Classes When Not in Repeat Mode (Concluded)

CLASS	PI/DI	PI/DE	PE/DI	PE/DE	PR/DI	PR/DE
XIII	Source data in on-chip RAM:					
	3	3+d	3+2p	3+d+2p	3	3+d
	Source data in external memory:					
	4+d	4+2d	4+d+2p	4+2d+2p	4+d	4+2d
XIV	Table in on-chip RAM:					
	3	3+d	4+2p	4+d+2p	4	4+d
	Table in on-chip ROM:					
	4	4+d	4+2p	4+d+2p	4	4+d
	Table in external memory:					
	4+p	4+d+p	4+3p	4+d+3p	4+p	4+d+p
XV	(Interrupt) destination on-chip ROM 3 (minimum waits for INT) (Interrupt) destination external memory 3+2p (minimum waits for INT)					

Table D–3. Cycle Timings for Cycle Classes When in Repeat Mode

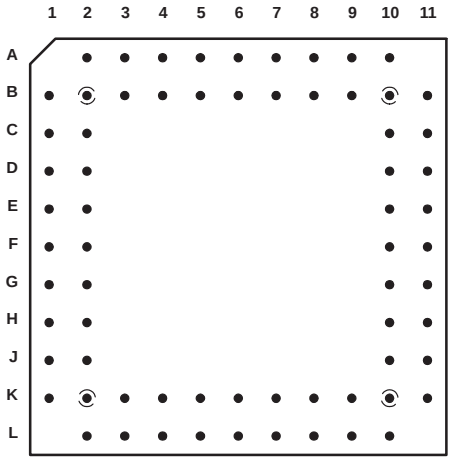
CLASS	PI/DI	PI/DE	PE/DI	PE/DE	PR/DI	PR/DE
I	n	1+n+nd	n+p	1+n+nd+p	n	1+n+nd
II	n	2n+nd	n+p	2n+nd+p	n	2n+nd
III	n	n+nd	n+p	1+n+nd+p	n	n+nd
IV	n	n	n+p	n+p	n	n
V	not repeatable					
VI	Table in on-chip RAM:					
	2+n	2+2n+nd	3+n+2p	3+2n+nd+2p	3+n	3+2n+nd
	Table in on-chip ROM:					
	3+n	3+2n+nd	3+n+2p	3+2n+nd+2p	3+n	3+2n+nd
	Table in external memory:					
	3+n+np	3+2n+nd+np	3+n+np+2p	3+2n+nd+np +2p	3+n+np	3+2n+nd+np
VII	not repeatable					
VIII	not repeatable					
IX	1+n+ni	2n+nd+ni	1+n+p+ni	1+2n+nd+p +ni	1+n+ni	2n+nd+ni
X	n+ni	2n+nd+ni	1+n+p+ni	1+2n+nd+p +ni	n+ni	2n+nd+ni
XI	Table in on-chip RAM:					
	1 + n	1 + n + nd	2+n+p	2+n+nd+p	2+n	2+n+nd
	Table in on-chip ROM:					
	2+n	2+n+nd	3+n+p	3+n+nd+p	3+n	3+n+nd
	Table in external memory:					
	2+n+np	1+2n+nd+np	3+n+np+p	2+2n+nd+np +p	3+n+np	2+2n+nd+np
XII	Table in on-chip RAM:					
	1+n	2+n+nd	2+n+p	3+n+nd+p	2+n	3+n+nd
	Table in on-chip ROM:					
	not applicable					
	Table in external memory:					
	1+n+np	1+2n+nd+np	2+n+np+p	2+2n+nd+np+p	2+n+np	2+2n+nd+np
XIII	Source data in on-chip RAM:					
	2+n	2+n+nd	2+n+2p	2+n+nd+2p	2+n	2+n+nd
	Source data in external memory:					
	3+n+nd	2+2n+2nd	3+n+nd+2p	2+2n+2nd +2p	3+n+nd	2+2n+2nd
XIV	Table in on-chip RAM:					
	2+n	2+n+nd	3+n+2p	3+n+nd+2p	3+n	3+n+nd
	Table in on-chip ROM:					
	3+n	3+n+nd	3+n+2p	3+n+nd+2p	3+n	3+n+nd
	Table in external memory:					
	3+n+np	2+2n+nd+np	3+n+np+2p	2+2n+nd+np +2p	3+n+np	2+2n+nd+np
XV	not repeatable					

Appendix E

SMJ320C2x Digital Signal Processors

This appendix contains data sheet information on the SMJ320C2x digital signal processors family.

68-PIN GB
PIN GRID ARRAY CERAMIC PACKAGE†
(TOP VIEW)



†See Pin Assignments Table (Page 2) and Pin Nomenclature Table (Page 3) for location and description of all pins.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

Copyright © 1992, Texas Instruments Incorporated

- **100-ns Instruction Cycle Time**
- **1568 Words of Configurable On-Chip Data/Program RAM**
- **256 Words of On-Chip Program ROM**
- **128K Words of Data/Program Space**
- **Pin-for-Pin Compatible with the SMJ320C25**
- **16 Input and 16 Output Channels**
- **16-Bit Parallel Interface**
- **Directly Accessible External Data Memory Space**
- **Global Data Memory Interface**
- **16-Bit Instruction and Data Words**
- **32-Bit ALU and Accumulator**
- **Single-Cycle Multiply/Accumulate Instructions**
- **0 to 16-Bit Scaling Shifter**
- **Bit Manipulation and Logical Instructions**
- **Instruction Set Support for Floating-Point Operations, Adaptive Filtering, and Extended-Precision Arithmetic**
- **Block Moves for Data/Program Management**
- **Repeat Instructions for Efficient Use of Program Space**
- **Eight Auxiliary Registers and Dedicated Arithmetic Unit for Indirect Addressing**
- **Serial Port for Direct Codec Interface**
- **Synchronization Input for Multiprocessor Configurations**
- **Wait States for Communications to Slow Off-Chip Memories/Peripherals**
- **On-Chip Timer for Control Operations**
- **Three External Maskable User Interrupts**
- **Input Pin Polled by Software Branch Instruction**
- **Programmable Output Pin for Signalling External Devices**
- **1.6-μm CMOS Technology**
- **Single 5-V Supply**
- **Packaging:**
  - **68-Pin Leaded Ceramic Chip Carrier (FJ Suffix)**
  - **68-Pin Leadless Ceramic Chip Carrier (FD Suffix)**
  - **68-Pin Grid Array Ceramic Package (GB Suffix)**
- **Military Operating Temperature Range . . . – 55° to 125°C**

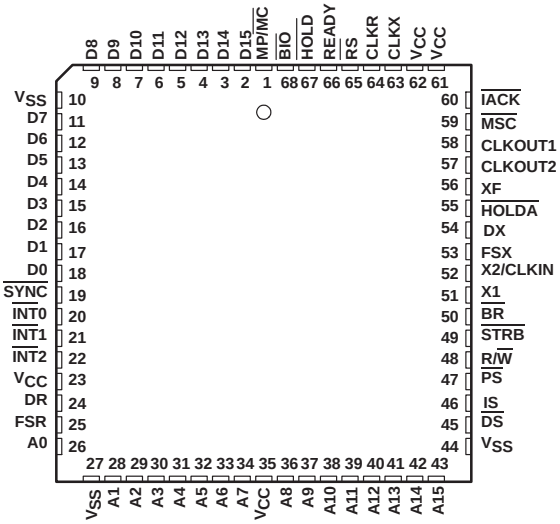
description

The SMJ320C26 Digital Signal Processor is a member of the TMS320 family of VLSI digital signal processors and peripherals. The TMS320 family supports a wide range of digital signal processing applications, such as telecommunications, modems, image processing, speech processing, spectrum analysis, audio processing, digital filtering, high-speed control, graphics, and other computation intensive applications.

With a 100-ns instruction cycle time and an innovative memory configuration, the SMJ320C26 performs operations necessary for many real time digital signal processing algorithms. Since most instructions require only one cycle, the SMJ320C26 is capable of executing ten million instructions per second. On-chip programmable data/program RAM of 1568 words of 16 bits, on-chip program ROM of 256-words, direct addressing of up to 64K-words of external program and 64K-words of data memory space, and multiprocessor interface features for sharing global memory minimize unnecessary data transfers to take full advantage of the capabilities of the processor.

The SMJ320C26 scaling shifter has a 16-bit input connected to the data bus and a 32-bit output connected to the ALU. The scaling shifter produces a left shift of 0 to 16 bits on the input data, as programmed in the instruction. The LSBs of the output are filled with zeroes, and the MSBs may be either filled with zeroes or sign-extended, depending upon the status programmed into the SXM (sign-extension mode) bit of status register ST1.

68-PIN FJ AND FD
LEADED AND LEADLESS
CERAMIC CHIP CARRIER PACKAGES†
(TOP VIEW)



† See Pin Assignments Table (Page 2) and Pin Nomenclature Table (Page 3) for location and description of all pins.

PGA/LCCC/JLCC PIN ASSIGNMENTS

FUNCTION	PIN	FUNCTION	PIN	FUNCTION	PIN	FUNCTION	PIN	FUNCTION	PIN	FUNCTION	PIN
A0	K1/26	A12	K8/40	D2	E1/16	D14	A5/3	INT2	H1/22	V_{CC}	H2/23

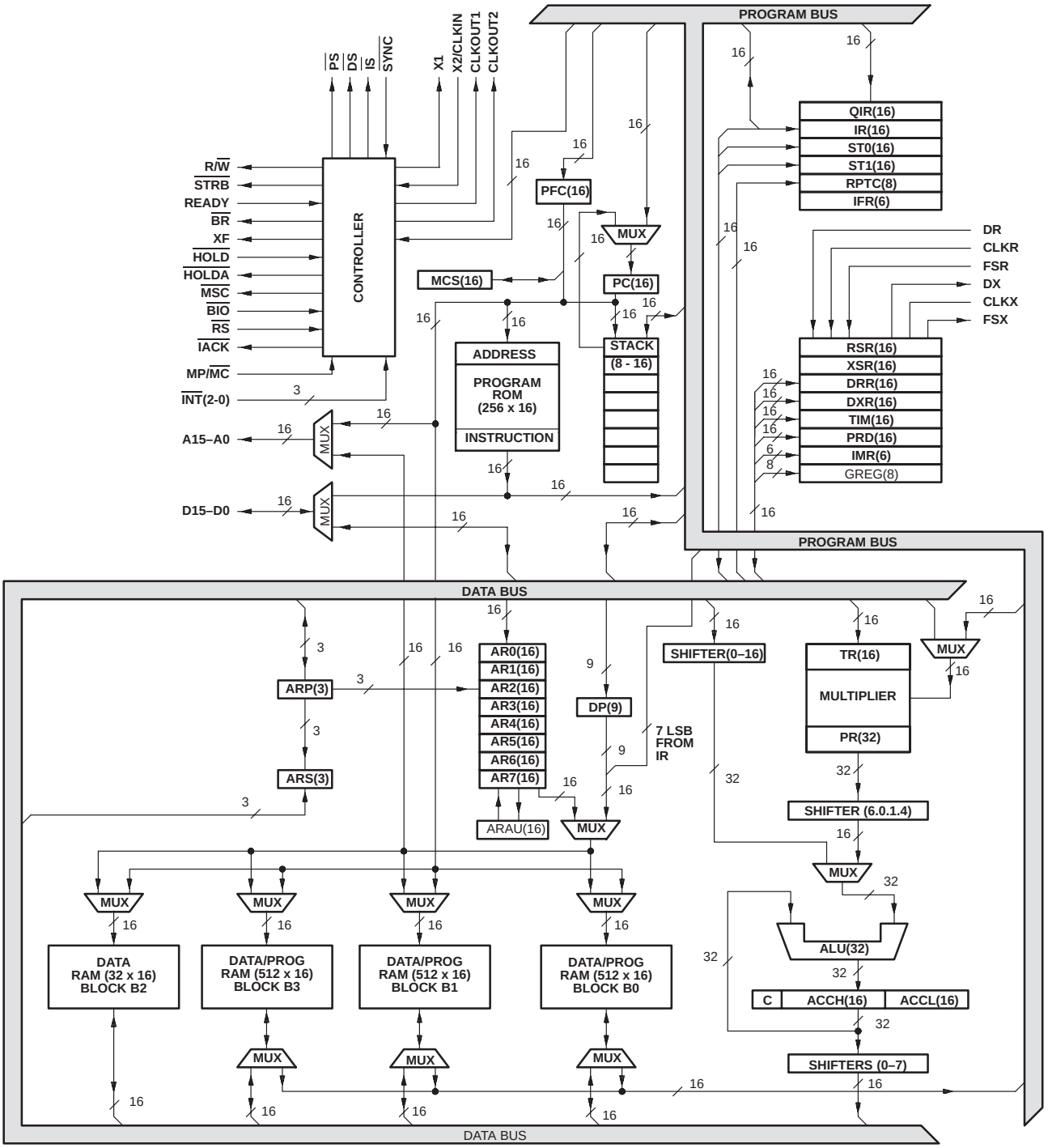
A1	K2/28	A13	L9/41	D3	D2/15	D15	B6/2	$\overline{IS}$	J11/46	V_{CC}	L6/35
A2	L3/29	A14	K9/42	D4	D1/14	$\overline{DR}$	J1/24	MP/$\overline{MC}$	A6/1	V_{SS}	B1/10
A3	K3/30	A15	L10/43	D5	C2/13	$\overline{DS}$	K10/45	$\overline{MSC}$	C10/59	V_{SS}	K11/44
A4	L4/31	$\overline{BIO}$	B7/68	D6	C1/12	DX	E11/54	$\overline{PS}$	J10/47	V_{SS}	L2/27
A5	K4/32	$\overline{BR}$	G11/50	D7	B2/11	FSR	J2/25	READY	B8/66	XF	D11/56
A6	L5/33	CLKOUT1	C11/58	D8	A2/9	FSX	F10/53	$\overline{RS}$	A8/65	X1	G10/51
A7	K5/34	CLKOUT2	D10/57	D9	B3/8	$\overline{HOLD}$	A7/67	R/$\overline{W}$	H11/48	X2/CLKIN	F11/52
A8	K6/36	CLKR	B9/64	D10	A3/7	$\overline{HOLDA}$	E10/55	$\overline{STRB}$	H10/49		
A9	L7/37	CLKX	A9/63	D11	B4/6	$\overline{IACK}$	B11/60	$\overline{SYNC}$	F2/19		
A10	K7/38	D0	F1/18	D12	A4/5	$\overline{INT0}$	G1/20	V_{CC}	A10/61		
A11	L8/39	D1	E2/17	D13	B5/4	$\overline{INT1}$	G2/21	V_{CC}	B10/62		

PIN NOMENCLATURE

NAME	I/O/Z†	DEFINITION
V_{CC}	I	5-V supply pins.
V_{SS}	I	Ground pins.
X1	O	Output from internal oscillator for crystal.
X2/CLKIN	I	Input to internal oscillator from crystal or external clock.
CLKOUT1	O	Master clock output (crystal or CLKIN frequency/4).
CLKOUT2	O	A second clock output signal.
D15–D0	I/O/Z	16-bit data bus D15 (MSB) through D0 (LSB). Multiplexed between program, data and I/O spaces.
A15–A0	O/Z	16-bit address bus A15 (MSB) through A0 (LSB).
$\overline{PS}$, $\overline{DS}$, $\overline{IS}$	O/Z	Program, data and I/O space select signals.
R/$\overline{W}$	O/Z	Read/write signal.
$\overline{STRB}$	O/Z	Strobe signal.
$\overline{RS}$	I	Reset input.
$\overline{INT2}$, $\overline{INT1}$, $\overline{INT0}$	I	External user interrupt inputs.
MP/$\overline{MC}$	I	Microprocessor/microcomputer mode select pin.
$\overline{MSC}$	O	Microstate complete signal.
$\overline{IACK}$	O	Interrupt acknowledge signal.
READY	I	Data ready input. Asserted by external logic when using slower devices to indicate that the current bus transaction is complete.
$\overline{BR}$	O	Bus request signal. Asserted when the SMJ320C26 requires access to an external global data memory space.
XF	O	External flag output (latched software – programmable signal).
$\overline{HOLD}$	I	Hold input. When asserted, SMJ320C26 goes into an idle mode and places the data address and control lines in the high-impedance state.
$\overline{HOLDA}$	O	Hold acknowledge signal.
$\overline{SYNC}$	I	Synchronization input.
$\overline{BIO}$	I	Branch control input. Polled by BIOZ instruction.
DR	I	Serial data receive input.
CLKR	I	Clock input for serial port receiver.
FSR	I	Frame synchronization pulse for receive input.
DX	O/Z	Serial data transmit output.
CLKX	I	Clock input for serial port transmitter.
FSX	I/O/Z	Frame synchronization pulse for transmit. May be configured as either an input or an output.

† I/O/Z denotes input/output/high-impedance state.

functional block diagram



LEGEND:

ACCH	=	Accumulator high	IFR	=	Interrupt flag register	PC	=	Program counter
ACCL	=	Accumulator low	IMR	=	Interrupt mask register	PFC	=	Prefetch counter
ALU	=	Arithmetic logic unit	IR	=	Instruction register	RPTC	=	Repeat instruction counter
ARAU	=	Auxiliary register arithmetic unit	MCS	=	Microcall stack	GREG	=	Global memory allocation register
ARS	=	Auxiliary register pointer buffer	QIR	=	Queue instruction register	RSR	=	Serial port receive shift register
ARP	=	Auxiliary register pointer	PR	=	Product register	XSR	=	Serial port to transmit shift register
DP	=	Data memory page pointer	PRD	=	Product register for timer	AR0–AR7	=	Auxiliary registers
DRR	=	Serial port data receive register	TIM	=	Timer	ST0, ST1	=	Status registers
DXR	=	Serial port data trademark register	TR	=	Temporary register	C	=	Carry bit

architecture

The SMJ320C26 architecture is based on the SMJ320C25 with a different internal RAM and ROM configuration. The SMJ320C26 integrates 256 words of on-chip ROM and 1568 words of on-chip RAM compared to 4K words of on-chip ROM and 544 words of on-chip RAM for the SMJ320C25. The SMJ320C26 is pin for pin compatible with the SMJ320C25.

Increased throughput on the SMJ320C26 for many DSP applications is accomplished by means of single cycle multiply/accumulate instructions with a data move option, eight auxiliary registers with a dedicated arithmetic unit, and faster I/O necessary for data intensive signal processing.

The architectural design of the SMJ320C26 emphasizes overall speed, communication, and flexibility in the processor configuration. Control signals and instructions provide floating point support, block memory transfers, communication to slower off-chip devices, and multiprocessing implementations.

Three large on-chip RAM blocks, configurable either as separate program and data spaces or as three contiguous data blocks, provide increased flexibility in system design. Programs of up to 256 words can be masked into the internal program ROM. The remainder of the 64K-word program memory space is located externally. Large programs can execute at full speed from this memory space. Programs can also be downloaded from slow external memory to high speed on-chip RAM. A data memory address space of 64K words is included to facilitate implementation of DSP algorithms. The VLSI implementation of the SMJ320C26 incorporates all of these features as well as many others, including a hardware timer, serial port, and block data transfer capabilities.

32-bit ALU accumulator

The SMJ320C26 32-bit Arithmetic Logic Unit (ALU) and accumulator perform a wide range of arithmetic and logic instructions, the majority of which execute in a single clock cycle. The ALU executes a variety of branch instructions dependent on the status of the ALU or a single bit in a word. These instructions provide the following capabilities:

- ❑ Branch to an address specified by the accumulator.
- ❑ Normalize fixed point numbers contained in the accumulator.
- ❑ Test a specified bit of a word in data memory.

One input to the ALU is always provided from the accumulator, and the other input may be provided from the Product Register (PR) of the multiplier or the input scaling shifter which has fetched data from the RAM on the data bus. After the ALU has performed the arithmetic or logical operations, the result is stored in the accumulator.

The 32-bit accumulator is split into two 16-bit segments for storage in data memory. Additional shifters at the output of the accumulator perform shifts while the data is being transferred to the data bus for storage. The contents of the accumulator remain unchanged.

scaling shifter

The SMJ320C26 scaling shifter has a 16-bit input connected to the data bus and a 32-bit output connected to the ALU. The scaling shifter produces a left shift of 0 to 16-bits on the input data, as specified in the instruction word. The LSBs of the output are filled with zeroes, and the MSBs may be either filled with zeroes or sign extended, depending upon the value of the SXM (sign extension mode) bit of status register STO.

16 × 16 bit parallel multiplier

The SMJ320C26 has a 16 × 16 bit-hardware multiplier, which is capable of computing a signed or unsigned 32-bit product in a single machine cycle. The multiplier has the following two associated registers:

- A 16-bit Temporary Register (TR) that holds one of the operands for the multiplier, and
- A 32-bit Product Register (PR) that holds the product.

Incorporated into the SMJ320C26 instruction set are single-cycle multiply/accumulate instructions that allow both operands to be fetched simultaneously. The data for these operations may reside anywhere in internal or external memory, and can be transferred to the multiplier each cycle via the program and data buses.

Four product shift modes are available at the Product Register (PR) output that are useful when performing multiply/accumulate operations, fractional arithmetic, or justifying fractional products.

timer

The SMJ320C26 provides a memory mapped 16-bit timer for control operations. The on-chip timer (TIM) register is a down counter that is continuously clocked by CLKOUT1. A timer interrupt (TINT) is generated every time the timer decrements to zero, provided the timer interrupt is enabled. The timer is reloaded with the value contained in the period (PRD) register within the next cycle after it reaches zero so that interrupts may be programmed to occur at regular intervals of PRD + 1 cycles of CLKOUT1.

memory control

The SMJ320C26 provides a total of 1568 words of 16 bit on-chip RAM, divided into four separate blocks (B0, B1, B2, and B3). Of the 1568 words, 32 words

(block B2) are always data memory, and all other blocks are programmable as either data or program memory. A data memory size of 1568 words allows the SMJ320C26 to handle a data array of 1536 words, while still leaving 32 locations for intermediate storage. When using B0, B1, or B3 as program memory, instructions can be downloaded from external memory into on-chip RAM, and then executed.

When using on-chip program RAM, ROM, or high speed external program memory, the SMJ320C26 runs at full speed without wait states. However, the READY line can be used to interface the SMJ320C26 to slower, less expensive external memory. Downloading programs from slow off-chip memory to on-chip program RAM speeds processing and cuts overall system costs.

The SMJ320C26 provides three separate address spaces for program memory, data memory, and I/O. The on-chip memory is mapped into either the data memory or program memory space, depending upon the choice of memory configuration.

The instruction configuration (parameter) is used as follows to configure the blocks B0, B1, and B3 as program or as data memory.

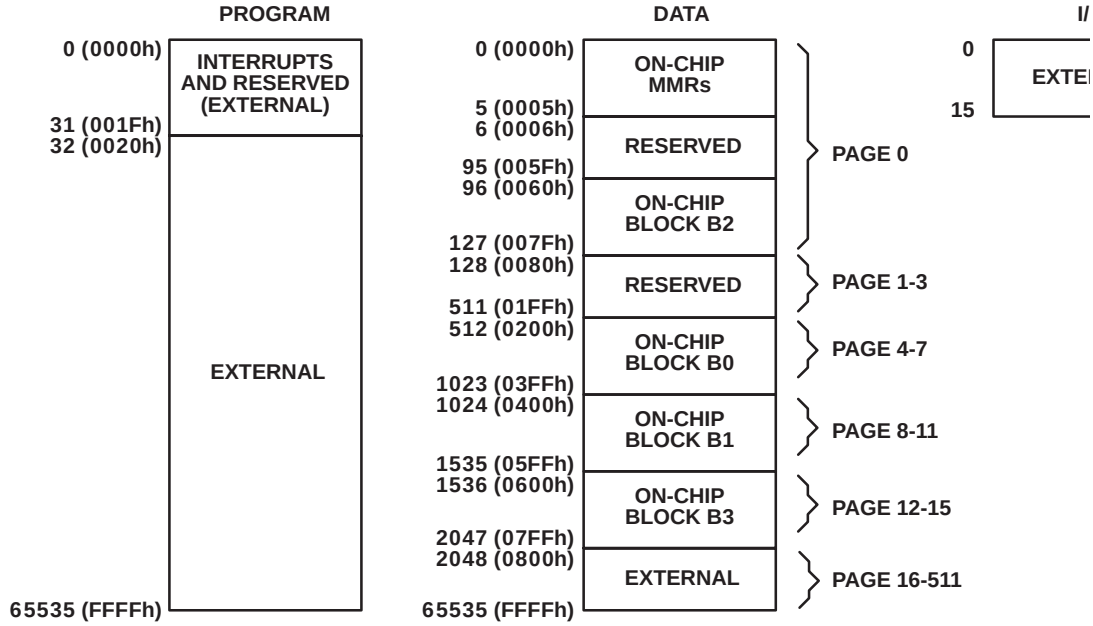
CONFIGURATION	B0	B1	B3
0	Data	Data	Data
1	Program	Data	Data
2	Program	Program	Data
3	Program	Program	Program

Regardless of the configuration, the user may still execute from external program memory.

The SMJ320C26 provides a ROM of 256 words. The ROM is sufficient to allow the programming of a bootstrap program and interrupt handler, or to implement self test routines.

The SMJ320C26 has six registers that are mapped into the data memory space at the locations 0–5; a serial port data receive register, serial port data transmit register, timer register, period register, interrupt mask register, and global memory allocation register.

MEMORY MAPS AFTER A RESET OR CONF 0
1 MP/MC = 1



2 MP/$\overline{\text{MC}}$ = 0

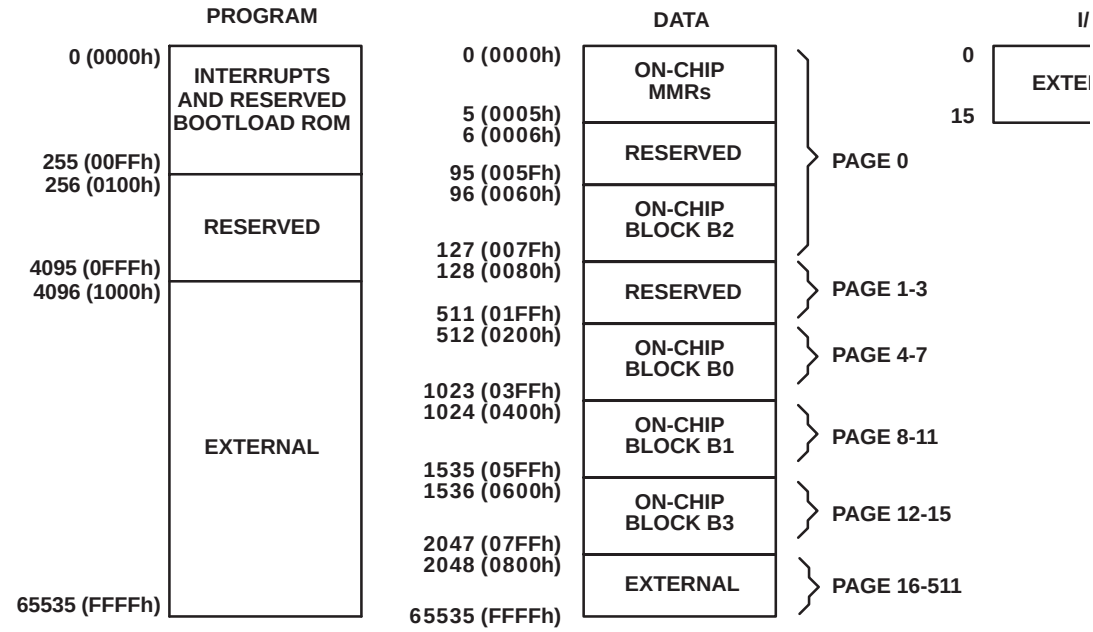
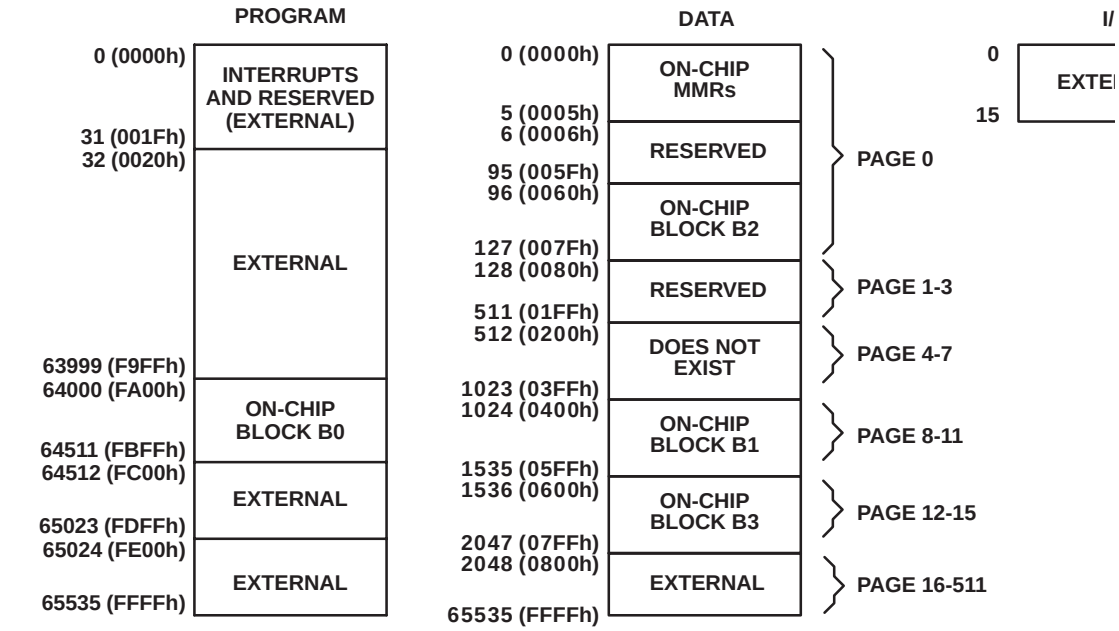


Figure 1A. Memory Maps

MEMORY MAPS AFTER CONF 1
1 MP/MC = 1



2 MP/$\overline{MC}$ = 0

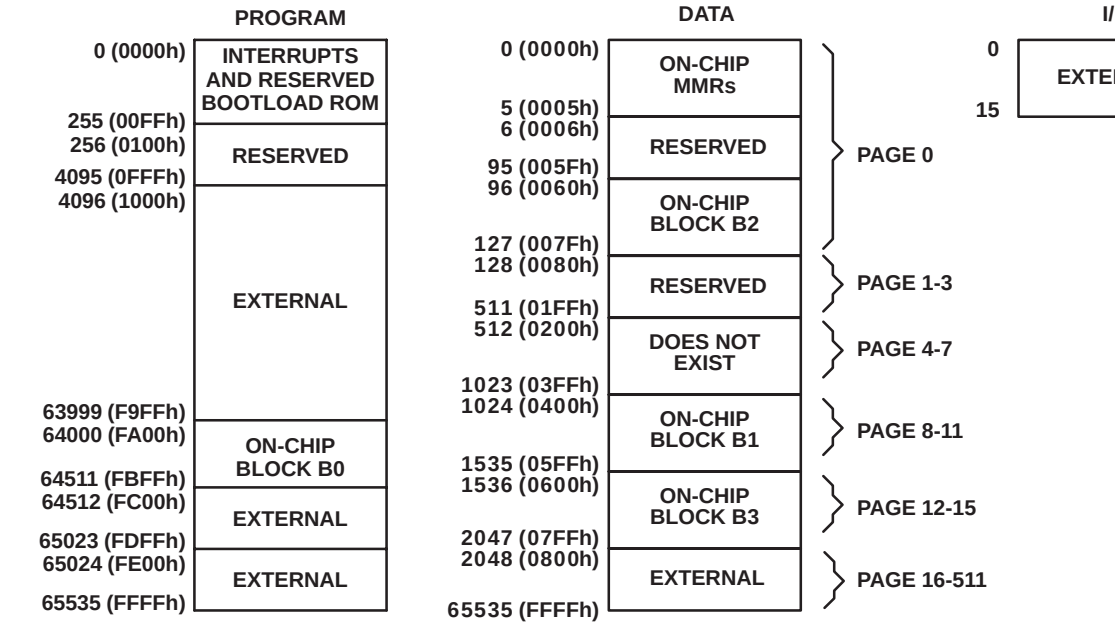
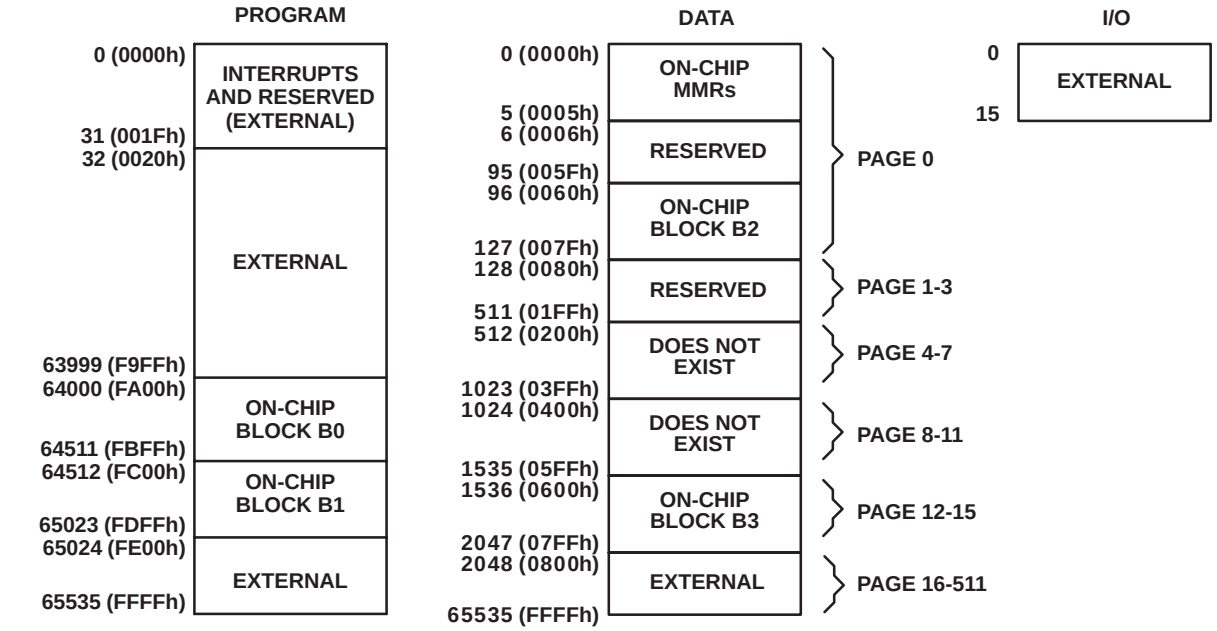


Figure 1B. Memory Maps

MEMORY MAPS AFTER CONF 2
1 MP/MC = 1



2 MP/$\overline{\text{MC}}$ = 0

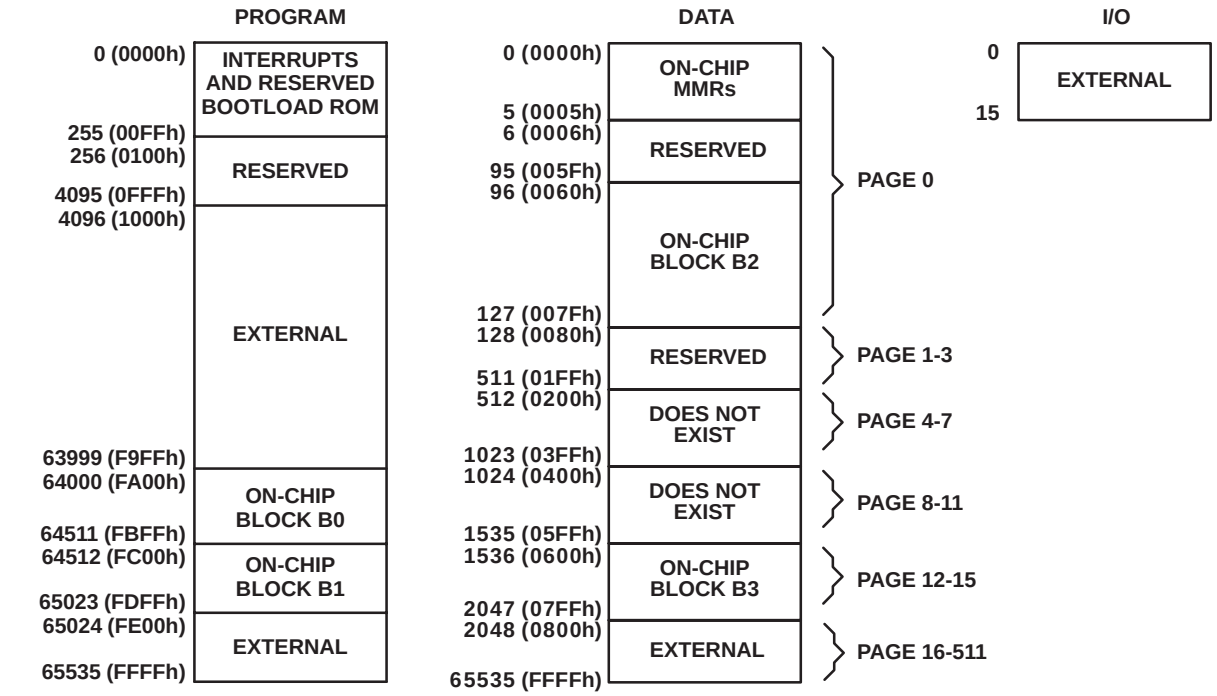
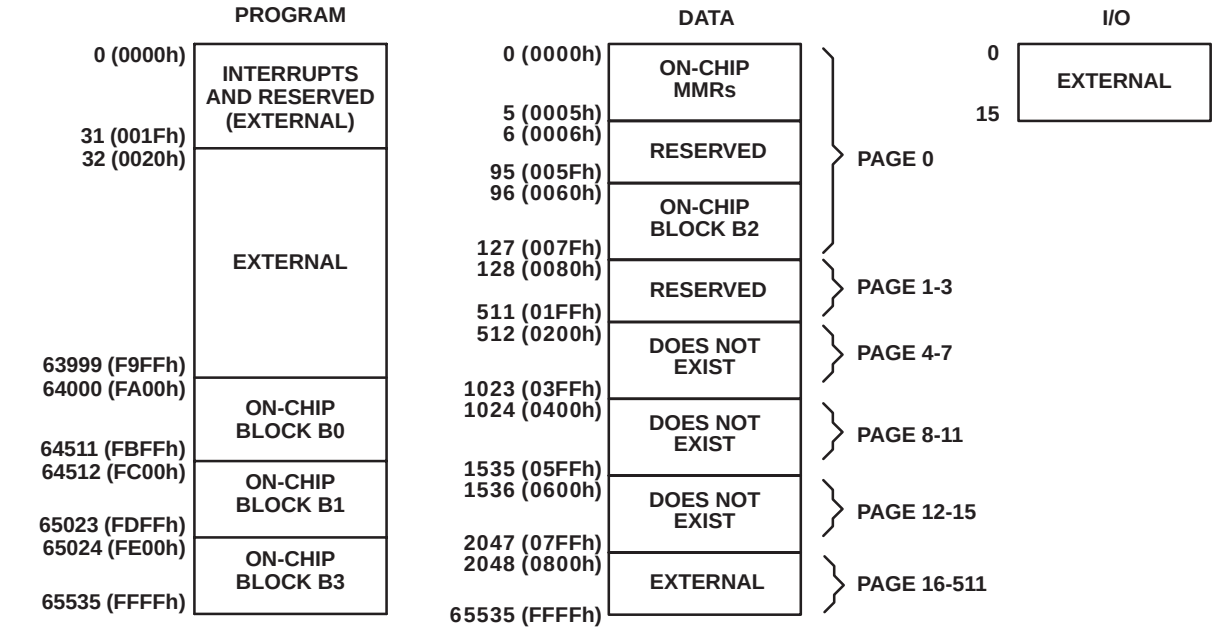


Figure 1C. Memory Maps

MEMORY MAPS AFTER CONF 3
1 MP/MC = 1



2 MP/$\overline{\text{MC}}$ = 0

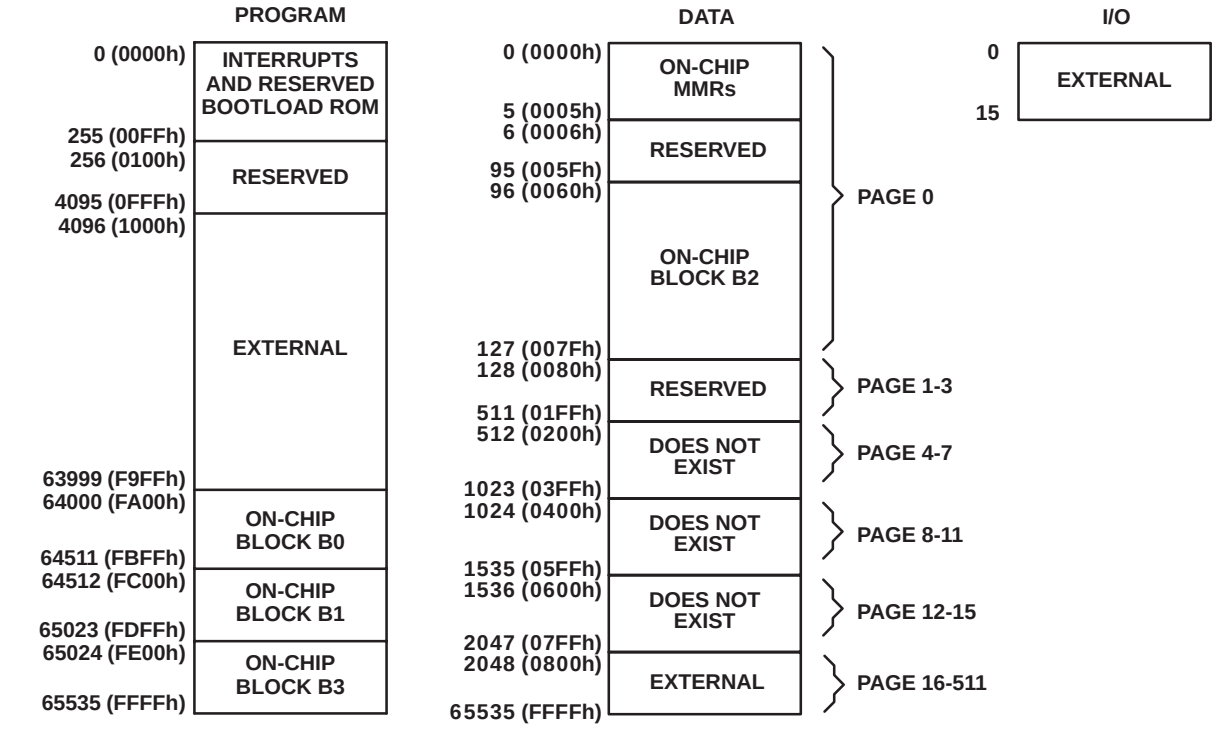


Figure 1D. Memory Maps

interrupts and subroutines

The SMJ320C26 has three external maskable user interrupts $\overline{\text{INT}}$2–$\overline{\text{INT}}$0, available for external devices that interrupt the processor. Internal interrupts are generated by the serial port (RINT and XINT), by the timer (TINT), and by the software interrupt (TRAP) instruction. Interrupts are prioritized with reset ($\overline{\text{RS}}$) having the highest priority and the serial port transmit interrupt (XINT) having the lowest priority. All interrupt locations are on two-words boundaries so that branch instructions can be accommodated in those locations if desired.

A built in mechanism protects multicycle instructions from interrupts. If an interrupt occurs during a multicycle instruction, the interrupt is not processed until the instruction is completed. This mechanism applies both to instructions that are repeated or become multicycle due to the READY signal.

external interface

The SMJ320C26 supports a wide range of system interfacing requirements. Program, data, and I/O address spaces provide interface to memory and I/O, thus maximizing system throughput. I/O design is simplified by having I/O treated the same way as memory. I/O devices are mapped into the I/O address space using the processor's external address and data busses in the same manner as memory-mapped devices. Interface to memory and I/O devices of varying speeds is accomplished by using the READY line. When transactions are made with slower devices, the SMJ320C26 processor waits until the other device completes its function and signals the processor via the READY line, the SMJ320C26 then continues execution.

A serial port provides communication with serial devices, such as codecs, serial A/D converters, and other serial systems. The interface signals are compatible with codecs and many other serial devices with a minimum of external hardware. The serial port may also be used for intercommunication between processors in multiprocessing applications.

The serial port has two memory mapped registers; the data transmit register (DXR) and the data receive register (DRR). Both registers operate in either the byte mode or 16-bit word mode, and may be accessed in the same manner as any other data memory location. Each register has an external clock, a framing signal, and associated shift registers. One method of multiprocessing may be implemented by programming one device to transmit while the others are in the receive mode.

multiprocessing

The flexibility of the SMJ320C26 allows configurations to satisfy a wide range of system requirements. The SMJ320C26 can be used as follows:

- A standalone processor.
- A multiprocessor with devices in parallel.
- A multiprocessor with global memory space.
- A peripheral processor interfaced via processor controlled signals to another device.

For multiprocessing applications, the SMJ320C26 has the capability of allocating global data memory space and communicating with that space via the $\overline{\text{BR}}$ (bus request) and READY control signals. Global memory is data memory shared by more than one processor. Global data memory access must be arbitrated. The 8-bit memory mapped GREG (global memory allocation register) specifies part of the SMJ320C26's data memory as global external memory. The contents of the register determine the size of the global memory space. If the current instruction addresses a location within that space, $\overline{\text{BR}}$ is asserted to request control of the data bus. The length of the memory cycle is controlled by the READY line.

The SMJ320C26 supports DMA (direct memory access) to its external program/data memory using the $\overline{\text{HOLD}}$ and $\overline{\text{HOLDA}}$ signals. Another processor can take complete control of the SMJ320C26's external memory by asserting $\overline{\text{HOLD}}$ low. This causes the SMJ320C26 to place its address, data, and control lines in a high impedance state, and assert $\overline{\text{HOLDA}}$.

addressing modes

The SMJ320C26 instruction set provides three memory addressing modes; direct, indirect, and immediate addressing.

Both direct and indirect addressing can be used to access data memory. In direct addressing, seven bits of the instruction word are concatenated with the nine bits of the data memory page pointer to form the 16-bit data memory address. Indirect addressing accesses data memory through the eight auxiliary registers. In immediate addressing, the data is embedded in the instruction word(s).

In direct addressing, the instruction word contains the lower seven bits of the data memory address. This field is concatenated with the nine bits of the data memory page pointer to form the full 16-bit address. Thus, memory is paged

in the direct addressing mode with a total of 512 pages, each page containing 128 words.

Eight auxiliary registers (AR0–AR7) provide flexible and powerful indirect addressing. To select a specific auxiliary register, the Auxiliary Register Pointer (ARP) is loaded with a value from 0 through 7 for AR0 through AR7 respectively.

There are seven types of indirect addressing: auto increment, auto decrement, post indexing by either adding or subtracting the contents of AR0, single indirect addressing with no increment or decrement and bit reversal addressing (used in FFTs) with increment or decrement. All operations are performed on the current auxiliary register in the same cycle as the original instruction, followed by an ARP update.

repeat feature

A repeat feature, used with instructions such as multiply/accumulates, block moves, I/O transfers, and table read/writes, allows a single instruction to be executed up to 256 times. The repeat counter (RPTC) is loaded with either a data memory value (RPT instruction) or an immediate value (RPTK instruction). The value of this operand is one less than the number of times that the next instruction is executed. Those instructions that are normally multicycle are pipelined when using the repeat feature, and effectively become single-cycle instructions.

instruction set

The SMJ320C26 microprocessor implements a comprehensive instruction set that supports both numeric intensive signal processing operations as well as general purpose applications, such as multiprocessing and high speed control.

For maximum throughput, the next instruction is prefetched while the current one is being executed. Since the same data lines are used to communicate to external data/program or I/O space, the number of cycles may vary depending upon whether the next data operand fetch is from internal or external program memory. Highest throughput is achieved by maintaining data memory on-chip and using either internal or fast program memory.

Table 1 lists the symbols and abbreviations used in Table 2, the instruction set summary. Table 2 consists primarily of single-cycle, single-word instructions. Infrequently used branch, I-O, and CALL instructions are multicycle. The instruction set summary is arranged according to function and alphabetized within each functional grouping. The symbol (‡) indicates instructions that are not included in the SMJ320C25 instruction set.

Table F–1. Instruction Symbols

SYMBOL	MEANING
B	4-bit field specifying a bit code

CM	2-bit field specifying compare mode
D	Data memory address field
FO	Format status bit
M	Addressing mode bit
K	Immediate operand field
PA	Port address (PA0 through PA 15 are predefined assembler symbols equal to 0 through 15 respectively).
PM	2-bit field specifying P register output shift code
R	3-bit operand field specifying auxiliary register
S	4-bit left-shift code
CNF	Internal RAM configuration bits
X	3-bit accumulator left-shift field

Table F–2. Instruction Set Summary

ACCUMULATOR MEMORY REFERENCE INSTRUCTIONS																		
MNEMONIC	**DESCRIPTION**	**NO. WORDS**	**INSTRUCTION BIT CODE**															
			15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
ABS	Absolute value of accumulator	1	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	1
ADD	Add to accumulator with shift	1	0	0	0	0	←	S	→		M	←			D			→
ADDC	Add to accumulator with carry	1	0	1	0	0	0	0	1	1	M	←			D			→
ADDH	Add to high accumulator	1	0	1	0	0	1	0	0	0	M	←			D			→
ADDK	Add to accumulator short immediate	1	1	1	0	0	1	1	0	0	←				K			→
ADDS	Add to low accumulator with sign extension suppressed	1	0	1	0	0	1	0	0	1	M	←			D			→
ADDT†	Add to accumulator with shift specified by T register	1	0	1	0	0	1	0	1	0	M	←			D			→
ADLK†	Add to accumulator long immediate with shift	2	1	1	0	1	←	S	→	0	0	0	0	0	0	0	1	0
AND	AND with accumulator	1	0	1	0	0	1	1	1	0	M	←			D			→
ANDK†	AND immediate with accumulator with shift	2	1	1	0	1	←	S	→		0	0	0	0	0	1	0	0
CMPL†	Complement accumulator	1	1	1	0	0	1	1	1	0	0	0	1	0	0	1	1	1
LAC	Load accumulator with shift	1	0	0	1	0	←	S	→		M	←			D			→
LACK	Load accumulator immediate short	1	1	1	0	0	1	0	1	0	←				K			→
LACT†	Load accumulator with shift specified by T register	1	0	1	0	0	0	0	1	1	M	←			D			→
LALK†	Load accumulator long immediate with shift	2	1	1	0	1	←	S	→		0	0	0	0	0	0	0	1
NEG†	Negate accumulator	1	1	1	0	0	1	1	1	0	0	0	1	0	0	0	1	1
NORM†	Normalize contents of accumulator	1	1	1	0	0	1	1	1	0	M	X	X	X	0	0	1	0
OR	OR with accumulator	1	0	1	0	0	1	1	0	1	M	←			D			→
ORK†	OR immediate with accumulator with shift	2	1	1	0	1	←	S	→		0	0	0	0	0	1	0	1
ROL	Rotate accumulator left	1	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0
ROR	Rotate accumulator right	1	1	1	0	0	1	1	1	0	0	0	1	1	0	1	0	1
SACH	Store high accumulator with shift	1	0	1	1	0	1	←	X	→	M	←			D			→
SACL	Store low accumulator with shift	1	0	1	1	0	0	←	X	→	M	←			D			→
SBLK†	Subtract from accumulator long immediate with shift	2	1	1	0	1	←	S	→		0	0	0	0	0	0	1	1
SFL†	Shift accumulator left	1	1	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0
SFR†	Shift accumulator right	1	1	1	0	0	1	1	1	0	0	0	0	1	1	0	0	1
SUB	Subtract from accumulator with shift	1	0	0	0	1	←	S	→		M	←			D			→
SUBB	Subtract from accumulator with borrow	1	0	1	0	0	1	1	1	1	M	←			D			→
SUBC	Conditional subtract	1	0	1	0	0	0	1	1	1	M	←			D			→
SUBH	Subtract from high accumulator	1	0	1	0	0	0	1	0	0	M	←			D			→
SUBK	Subtract from accumulator short immediate	1	1	1	0	0	1	1	0	1	←				K			→
SUBS	Subtract from low accumulator with sign extension suppressed	1	0	1	0	0	0	1	0	1	M	←			D			→
SUBT†	Subtract from accumulator with shift specified by T register	1	0	1	0	0	0	1	1	0	M	←			D			→
XOR	Exclusive-OR with accumulator	1	0	1	0	0	1	1	0	0	M	←			D			→
XORK†	Exclusive-OR immediate with accumulator with shift	2	1	1	0	1	←	S	→		0	0	0	0	0	1	1	0
ZAC	Zero accumulator	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0
ZALH	Zero low accumulator and load high accumulator	1	0	1	0	0	0	0	0	0	M	←			D			→
ZALR	Zero low accumulator and load high accumulator with rounding	1	0	1	1	1	1	0	1	1	M	←			D			→
ZALS	Zero accumulator and load low accumulator with sign extension suppressed	1	0	1	0	0	0	0	0	1	M	←			D			→

† These instructions are not included in the SMJ32010 instruction set.

Table 2. Instruction Set Summary (continued)

AUXILIARY REGISTERS AND DATA PAGE POINTER INSTRUCTIONS			
MNEMONIC	**DESCRIPTION**	**NO. WORDS**	**INSTRUCTION BIT CODE**
ADRK	Add to auxiliary register short immediate	1	0 1 1 1 1 1 1 0 K
CMPR†	Compare auxiliary register with auxiliary register AR0	1	1 1 0 0 1 1 1 0 0 1 0 CM 0
LAR	Load auxiliary register	1	0 0 1 R 0 M D
LARK	Load auxiliary register short immediate	1	1 1 0 R 0 K
LARP	Load auxiliary register pointer	1	0 1 0 1 0 1 0 1 M 0 0 0 R 1
LDP	Load data memory page pointer	1	0 1 0 1 0 0 1 0 M D
LDPK	Load data memory page pointer immediate	1	1 1 0 0 1 0 0 DP
LRLK†	Load auxiliary register long immediate	2	1 1 0 R 0 0 0 0 0 0 0 0 0 0
MAR	Modify auxiliary register	1	0 1 0 1 0 1 0 1 M D
SAR	Store auxiliary register	1	0 1 1 R 0 M D
SBRK	Subtract from auxiliary register short immediate	1	0 1 1 1 1 1 1 1 K

T REGISTER, P REGISTER, AND MULTIPLY INSTRUCTIONS			
MNEMONIC	**DESCRIPTION**	**NO. WORDS**	**INSTRUCTION BIT CODE**
APAC	Add P register to accumulator	1	1 1 0 0 1 1 1 0 0 0 0 1 0 1 0 1
LPH†	Load high P register	1	0 1 0 1 0 0 1 1 M D
LT	Load T register	1	0 0 1 1 1 1 0 0 M D
LTA	Load T register and accumulator previous product	1	0 0 1 1 1 1 0 1 M D
LTD	Load T register, accumulate previous product, and move data	1	0 0 1 1 1 1 1 1 M D
LTP†	Load T register and store P register in accumulator	1	0 0 1 1 1 1 1 0 M D
LTS†	Load T register and subtract previous product	1	0 1 0 1 1 0 1 1 M D
MAC†	Multiply and accumulate	2	0 1 0 1 1 1 0 1 M D
MACD†	Multiply and accumulate with data move	2	0 1 0 1 1 1 0 0 M D
MPY	Multiply (with T register, store product in P register)	1	0 0 1 1 1 0 0 0 M D
MPYA	Multiply and accumulate previous product	1	0 0 1 1 1 0 1 0 M D
MPYK	Multiply immediate	1	1 0 1 K
MPYS	Multiply and subtract previous product	1	0 0 1 1 1 0 1 1 M D
MPYU	Multiply unsigned	1	1 1 0 0 1 1 1 1 M D
PAC	Load accumulator with P register	1	1 1 0 0 1 1 1 0 0 0 0 1 0 1 0 0
SPAC	Subtract P register from accumulator	1	1 1 0 0 1 1 1 0 0 0 0 1 0 1 1 0
SPH	Store high P register	1	0 1 1 1 1 1 0 1 M D
SPL	Store low P register	1	0 1 1 1 1 1 0 0 M D
SPM†	Set P register output shift mode	1	1 1 0 0 1 1 1 0 0 0 0 PM 0
SQRA†	Square and accumulate	1	0 0 1 1 1 0 0 1 M D
SQRS†	Square and subtract previous product	1	0 1 0 1 1 0 1 0 M D

† These instructions are not included in the SMJ32010 instruction set.

Table 2. Instruction Set Summary (continued)

BRANCH/CALL INSTRUCTIONS																		
MNEMONIC	**DESCRITPION**	**NO. WORDS**	**INSTRUCTION BIT CODE**															
			15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
B	Branch unconditionally	2	1	1	1	1	1	1	1	1	D							
BACC†	Branch to address specified by accumulator	1	1	1	0	0	1	1	1	0	0	0	1	0	0	1	0	1
BANZ	Branch on auxiliary register not zero	2	1	1	1	1	1	0	1	1	D							
BBNZ†	Branch if TC bit ≠ 0	2	1	1	1	1	1	0	0	1	D							
BBZ†	Branch if TC bit = 0	2	1	1	1	1	1	0	0	0	D							
BC	Branch on carry	2	0	1	0	1	1	1	1	0	D							
BGEZ	Branch if accumulator ≥ 0	2	1	1	1	1	0	1	0	0	D							
BGZ	Branch if accumulator > 0	2	1	1	1	1	0	0	0	1	D							
BIOZ	Branch on I/O status = 0	2	1	1	1	1	1	0	1	0	D							
BLEZ	Branch if accumulator ≤ 0	2	1	1	1	1	0	0	1	0	D							
BLZ	Branch if accumulator < 0	2	1	1	1	1	0	0	1	1	D							
BNC	Branch on no carry	2	0	1	0	1	1	1	1	1	D							
BNV†	Branch if no overflow	2	1	1	1	1	0	1	1	1	D							
BNZ	Branch if accumulator ≠ 0	2	1	1	1	1	0	1	0	1	D							
BV	Branch on overflow	2	1	1	1	1	0	0	0	0	D							
BZ	Branch if accumulator = 0	2	1	1	1	1	0	1	1	0	D							
CALA	Call subroutine indirect	1	1	1	0	0	1	1	1	0	0	0	1	0	0	1	0	0
CALL	Call subroutine	2	1	1	1	1	1	1	1	0	D							
RET	Return from subroutine	1	1	1	0	0	1	1	1	0	0	0	1	0	0	1	1	0
I/O AND DATA MEMORY OPERATIONS																		
MNEMONIC	**DESCRITPION**	**NO. WORDS**	**INSTRUCTION BIT CODE**															
			15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
BLKD	Block move from data memory to data memory	2	1	1	1	1	1	1	0	1	M D							
BLKP†	Block move from program memory to data memory	2	1	1	1	1	1	1	0	0	M D							
DMOV	Data move in data memory	1	0	1	0	1	0	1	1	0	M D							
FORT†	Format serial port registers	1	1	1	0	0	1	1	1	0	0	0	0	0	1	1	FO	
IN	Input data from port	1	1	0	0	0	PA				M D							
OUT	Output data to port	1	1	1	1	0	PA				M D							
RFSM	Reset serial port frame synchronization mode	1	1	1	0	0	1	1	1	0	0	0	1	1	0	1	1	0
RTXM†	Reset serial port transmit mode	1	1	1	0	0	1	1	1	0	0	0	1	0	0	0	0	0
RXF†	Reset external flag	1	1	1	0	0	1	1	1	0	0	0	0	0	1	1	0	0
SFSM	Set serial port frame synchronization mode	1	1	1	0	0	1	1	1	0	0	0	1	1	0	1	1	1
STXM†	Set serial port transmit mode	1	1	1	0	0	1	1	1	0	0	0	1	0	0	0	0	1
SXF†	Set external flag	1	1	1	0	0	1	1	1	0	0	0	0	0	1	1	0	1
TBLR	Table read	1	0	1	0	1	1	0	0	0	M D							
TBLW	Table write	1	0	1	0	1	1	0	0	1	M D							

† These instructions are not included in the SMJ32010 instruction set.

Table 2. Instruction Set Summary (concluded)

CONTROL INSTRUCTIONS																		
MNEMONIC	**DESCRIPTION**	**NO. WORDS**	**INSTRUCTION BIT CODE**															
			15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
BIT†	Test bit	1	1	0	0	1	D				M				D			
BITT†	Test bit specified by T register	1	0	1	0	1	0	1	1	1	M				D			
CONF‡	Configure RAM blocks as Data or program	1	1	1	0	0	1	1	1	0	0	0	1	1	CN	P		
DINT	Disable interrupt	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	1
EINT	Enable interrupt	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0
IDLE†	Idle until interrupt	1	1	1	0	0	1	1	1	0	0	0	0	1	1	1	1	1
LST	Load status register ST0	1	0	1	0	1	0	0	0	0	M				D			
LST1†	Load status register ST1	1	0	1	0	1	0	0	0	1	M				D			
NOP	No operation	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0
POP	Pop top of stack to low accumulator	1	1	1	0	0	1	1	1	0	0	0	0	1	1	1	0	1
POPD†	Pop top of stack to data memory	1	0	1	1	1	1	0	1	0	M				D			
PSHD†	Push data memory value onto stack	1	0	1	0	1	0	1	0	0	M				D			
PUSH	Push low accumulator onto stack	1	1	1	0	0	1	1	1	0	0	0	0	1	1	1	0	0
RC	Reset carry bit	1	1	1	0	0	1	1	1	0	0	0	1	1	0	0	0	0
RHM	Reset hold mode	1	1	1	0	0	1	1	1	0	0	0	1	1	1	0	0	0
ROVM	Reset overflow mode	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	1	0
RPT†	Repeat instruction as specified by data memory value	1	0	1	0	0	1	0	1	1	M				D			
RPTK†	Repeat instruction as specified by immediate value	1	1	1	0	0	1	0	1	1				K				
RSXM†	Reset sign-extension mode	1	1	1	0	0	1	1	1	0	0	0	0	0	0	1	1	0
RTC	Reset test/control flag	1	1	1	0	0	1	1	1	0	0	0	1	1	0	0	1	0
SC	Set carry bit	1	1	1	0	0	1	1	1	0	0	0	1	1	0	0	0	1
SHM	Set hold mode	1	1	1	0	0	1	1	1	0	0	0	1	1	1	0	0	1
SOVM	Set overflow mode	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	1	1
SST	Store status register ST0	1	0	1	1	1	1	0	0	0	M				D			
SST1†	Store status register ST1	1	0	1	1	1	1	0	0	1	M				D			
SSXM†	Set sign-extension mode	1	1	1	0	0	1	1	1	0	0	0	0	0	0	1	1	1
STC	Set test/control flag	1	1	1	0	0	1	1	1	0	0	0	1	1	0	0	1	1
TRAP†	Software interrupt	1	1	1	0	0	1	1	1	0	0	0	0	1	1	1	1	0

† These instructions are not included in the SMJ32010 instruction set.
‡ This instruction replaces CNFD and CNFP in the SMJ320C25 instruction set.

development support

Together, Texas Instruments and its authorized third-party suppliers offer an extensive line of development support products to assist the user in all aspects of TMS320 second-generation-based design and development. These products range from development and application software to complete hardware development and evaluation systems. Table 3 lists the development support products for the second-generation TMS320 devices.

System development may begin with the use of the simulator, Software Development System (SWDS), or emulator (XDS) along with an assembler/linker. These tools give the TMS320 user various means of evaluation, from software simulation of the second-generation TMS320s (simulator) to full-speed in-circuit emulation with hardware and software breakpoint trace and timing capabilities (XDS).

Software and hardware can be developed simultaneously by using the macro assembler/linker, C compiler, and simulator for software development, the XDS for hardware development, and the Software Development System for both software development and limited hardware development.

Many third-party vendors offer additional development support for the second-generation TMS320s, including assembler/linkers, simulators, high-level languages, applications software, algorithm development tools, applications boards, software development boards, and in-circuit emulators. Refer to the *TMS320 Family Development Support Reference Guide* (SPRU011A) for further information about TMS320 development support products offered by both Texas Instruments and its third-party suppliers.

Additional support for the TMS320 products consists of an extensive library of product and applications documentation. Three-day DSP design workshops are offered by the TI Regional Technology Centers (RTCs). These workshops provide insight into the architecture and the instruction set of the second-generation TMS320s as well as hands-on training with the TMS320 development tools. When technical questions arise regarding the TMS320 family, contact the Texas Instruments TMS320 Hotline at (713) 274–2320. Or, keep informed on the latest TI and third-party development support tools by accessing the DSP Bulletin Board Service (BBS) at (713) 274–2323. The BBS serves 2400-, 1200-, and 300-bps modems. Also, TMS320 application source code may be downloaded from the BBS.

Table 3 gives a complete list of SMJ320C26 software and hardware development tools.

Table F–3. Software and Hardware Support

MACRO ASSEMBLER/LINKER		
HOST COMPUTER	**OPERATING SYSTEMS**	**PART NUMBER**
DEC VAX	VMS	TMDS3242250-08
IBM PC	MS/PS DOS	TMDS3242850-02
VAX	ULTRIX	TMDS3242260-08
SUN 3	UNIX	TMDS3242550-08
C COMPILER AND MACRO ASSEMBLER/LINKER		
HOST COMPUTER	**OPERATING SYSTEMS**	**PART NUMBER**
DEC VAX	VMS	TMDS3242255-08
IBM PC	MS/PC DOS	TMDS3242855-02
VAX	ULTRIX	TMDS3242265-08
SUN 3	UNIX	TMDS3242555-08
SIMULATOR		
HOST COMPUTER	**OPERATING SYSTEMS**	**PART NUMBER**
DEC VAX	VMS	TMDS3242251-08
IBM PC	MS/PC DOS	TMDS3242851-02
EMULATOR		
MODEL	**POWER SUPPLY**	**PART NUMBER**
XDS/22	INCLUDED	TMDS3262292
SOFTWARE DEVELOPMENT SYSTEM ON PC		
HOST COMPUTER	**OPERATING SYSTEMS**	**PART NUMBER**
IBM PC	MS/PC DOS	TMDX3268828
IBM PC	MS/PC DOS	TMDX3268821†

† Includes assembler/linker

absolute maximum ratings over specified temperature range (unless otherwise noted)†

Supply voltage range, V_{CC}‡ . . . . . – 0.3 V to 7 V
Input voltage range . . . . . – 0.3 V to 7 V
Output voltage range . . . . . – 0.3 V to 7 V
Continuous power dissipation . . . . . 1.0 W
Storage temperature range . . . . . – 55°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions beyond those indicated in the “recommended operating conditions” section of this specification is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
‡ All voltages are with respect to V_{SS}.

This device contains circuits to protect its inputs and outputs against damage due to high static voltages or electrostatic fields. These circuits have been qualified to protect this device against electrostatic discharges (ESD) of up to 2 kV according to MIL-STD-883C, Method 3015; however, it is advised that precautions be taken to avoid application of any voltage higher than maximum-rated voltages to these high-impedance circuits. During storage or handling, the device leads should be shorted together or the device should be placed in conductive foam. In a circuit, unused inputs should always be connected to an appropriated logic voltage level, preferably either V_{CC} or ground. Specific guidelines for handling devices of this type are contained in the publication *Guidelines for Handling Electrostatic-Discharge-Sensitive (ESDS) Devices and Assemblies* available from Texas Instruments.

recommended operating conditions

			MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	V
V_{SS}	Supply voltage			0		V
V_{IH}	High-level input voltage	D15–D0, FSX	2.2			V
		CLKIN, CLKR, CLKX	3.50			
		All others	3.00			
V_{IL}	Low-level input voltage	D15–D0, FSX, CLKIN, CLKR, CLKX			0.8	µA
		All others			0.7	
I_{OH}	High-level output current				300	µA
I_{OL}	Low-level output current				2	mA
T_A	Minimum operating free-air temperature		–55			°C
T_C	Maximum operating case temperature				125	°C

electrical characteristics over specified free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP§	MAX	UNIT
V_{OH}	High-level output voltage	V_{CC} = MIN, I_{OH} = MAX	2.4	3		V
V_{OL}	Low-level output voltage	V_{CC} = MIN, I_{OL} = MAX		0.3	0.6	V

I_{OZ}	High-impedance-state output leakage current		V_{CC} = MAX	± 20	µA
I_I	Input current		$V_I = V_{SS}$ to V_{CC}	± 10	µA
I_{CC}	Supply current	Normal	V_{CC} = MAX, f_x = MAX	185	mA
		Idle/$\overline{\text{HOLD}}$		100	
C_I	Input capacitance			15	pF
C_O	Output capacitance			15	pF

§ All typical values are at V_{CC} = 5 V, T_A = 25°C.

CLOCK CHARACTERISTICS AND TIMING

The SMJ320C26 can use either its internal oscillator or an external frequency source for a clock.

internal clock option

The internal oscillator is enabled by connecting a crystal across X1 and X2/CLKIN (see Figure 2). The frequency of CLKOUT1 is one-fourth the crystal fundamental frequency. The crystal should be either fundamental or overtone mode, and parallel resonant, with an effective series resistance of 30 ohms, a power dissipation of 1 mW, and be specified at a load capacitance of 20 pF. Note that overtone crystals require an additional tuned LC circuit (see the application report, *Hardware Interfacing to the TMS320C25*).

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_X Input clock frequency†	T_A = –55°C MIN	6.7		40.0	MHz
C1, C2	T_C = 125°C MAX		10		pF

† This parameter is not production tested.

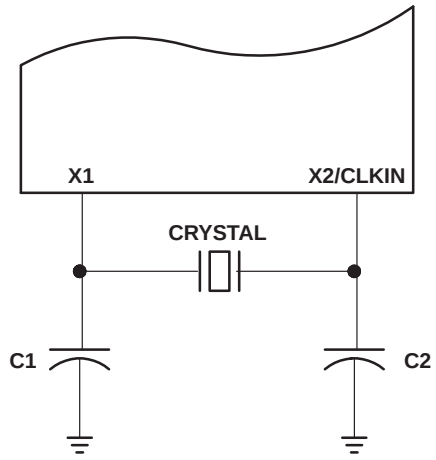


Figure 1. Internal Clock Option

external clock option

An external frequency source can be used by injecting the frequency directly into X2/CLKIN with X1 left unconnected. The external frequency injected must conform to the specifications listed in the table below.

switching characteristics over recommended operating conditions (see Note 1)

PARAMETER		MIN	TYP†	MAX	UNIT
$t_{c(C)}$	CLKOUT1/CLKOUT2 cycle time	100		600	ns

$t_{d(CIH-C)}$	CLKIN high to CLKOUT1/CLKOUT2/$\overline{STRB}$ high/low	5		32	ns
$t_{f(C)}$	CLKOUT1/CLKOUT2/$\overline{STRB}$ fall time			5	ns
$t_{r(C)}$	CLKOUT1/CLKOUT2/$\overline{STRB}$ rise time			5	ns
$t_{w(CL)}$	CLKOUT1/CLKOUT2 low pulse duration	2Q−8	2Q	2Q+8	ns
$t_{w(CH)}$	CLKOUT1/CLKOUT2 high pulse duration	2Q−8	2Q	2Q+8	ns
$t_{d(C1-C2)}$	CLKOUT1 high to CLKOUT2 low, CLKOUT2 high to CLKOUT1 high, etc.	Q−6	Q	Q+6	ns

† This parameter is not production tested.

NOTE 1: $Q = 1/4t_{c(C)}$

timing requirements over recommended operating conditions (see Note 1)

		MIN	NOM	MAX	UNIT
$t_{c(CI)}$	CLKIN cycle time	25		150	ns
$t_{w(CIL)}$	CLKIN low pulse duration, $t_{c(C)}$ = 25 ns (see Note 2)	10		15	ns
$t_{w(CIH)}$	CLKIN high pulse duration, $t_{c(CI)}$ = 25 ns (see Note 2)	10		15	ns
$t_{su(S)}$	$\overline{\text{SYNC}}$ setup time before CLKIN low	5		Q–5	ns
$t_{h(S)}$	$\overline{\text{SYNC}}$ hold time from CLKIN low	8			ns

NOTES: 1. $Q = 1/4t_{c(C)}$
2. CLKIN duty cycle $[t_{r(CI)} + t_{w(CIH)}]/t_{c(CI)}$ must be within 40-60%. CLKIN rise and fall times must be less than 5 ns.

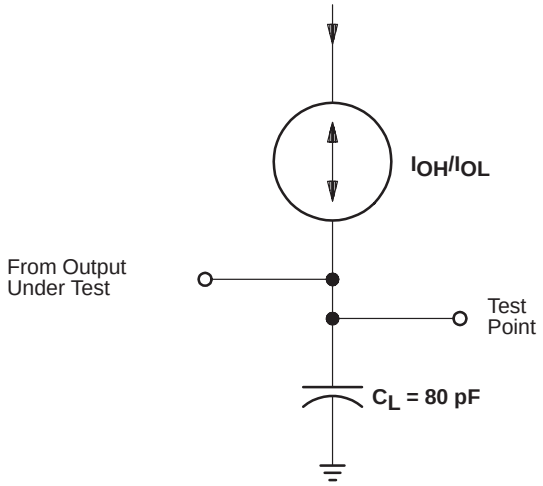
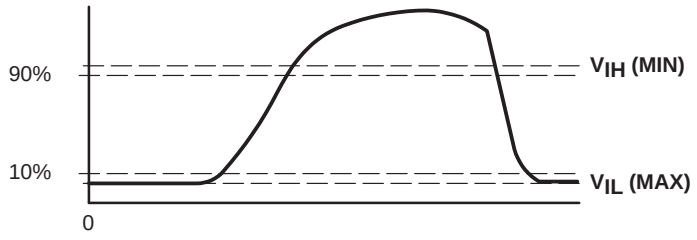
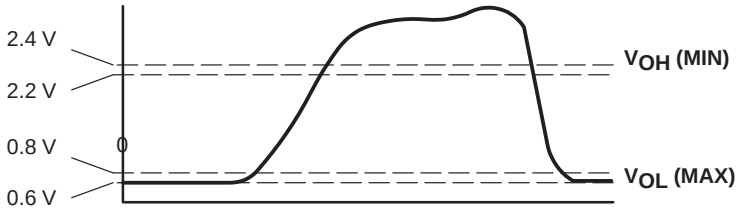


Figure 2. Test Load Circuit



(a) Input



(b) Outputs

Figure 3. Voltage Reference Levels

MEMORY AND PERIPHERAL INTERFACE TIMING

switching characteristics over recommended operating conditions (see Note 1)

PARAMETER		MIN	TYP	MAX	UNIT
$t_{d(C1-S)}$	$\overline{\text{STRB}}$ from CLKOUT1 (if $\overline{\text{STRB}}$ is present)	Q−6	Q	Q+6	ns
$t_{d(C2-S)}$	CLKOUT2 to $\overline{\text{STRB}}$ (if $\overline{\text{STRB}}$ is present)	−6	0	6	ns
$t_{su(A)}$	Address setup time before $\overline{\text{STRB}}$ low (see Note 3)	Q−12			ns
$t_{h(A)}$	Address hold time after $\overline{\text{STRB}}$ high (see Note 3)	Q−8			ns
$t_{w(SL)}$	$\overline{\text{STRB}}$ low pulse duration (no wait states, see Note 4)	2Q−5	2Q	2Q+5	ns
$t_{w(SH)}$	$\overline{\text{STRB}}$ high pulse duration (between consecutive cycles, see Note 4)		2Q		ns
$t_{su(D)W}$	Data write setup time before $\overline{\text{STRB}}$ high (no wait states)	2Q−20			ns
$t_{h(D)W}$	Data write hold time from $\overline{\text{STRB}}$ high	Q−10	Q		ns
$t_{en(D)}$	Data bus starts being driven after $\overline{\text{STRB}}$ low (write cycle)	0†			ns
$t_{dis(D)}$	Data bus three-state after $\overline{\text{STRB}}$ high (write cycle)		Q	Q+15†	ns
$t_{d(MSC)}$	$\overline{\text{MSC}}$ valid from CLKOUT1	−10†	0	10	ns

timing requirements over recommended operating conditions (see Note 1)

		MIN	NOM	MAX	UNIT
$t_{a(A)}$	Read data access time from address time (read cycle) (see Notes 3 and 5)			3Q−40	ns

$t_{su(D)R}$	Data read setup time before $\overline{STRB}$ high	23		ns
$t_{h(D)R}$	Data read hold time from $\overline{STRB}$ high	0		ns
$t_{d(SL-R)}$	READY valid after $\overline{STRB}$ low (no wait states)		Q–22	ns
$t_{d(C2H-R)}$	READY valid after CLKOUT2 high		Q – 22†	ns
$t_{h(SL-R)}$	READY hold time after $\overline{STRB}$ low (no wait states)	Q+3		ns
$t_{h(C2H-R)}$	READY hold after CLKOUT2 high	Q + 3†		ns
$t_{d(M-R)}$	READY valid after $\overline{MSC}$ valid		2Q –25†	ns
$t_{h(M-R)}$	READY hold time after $\overline{MSC}$ valid	0†		ns

$\overline{RS}$, $\overline{INT}$, $\overline{BIO}$, AND XF TIMING

switching characteristics over recommended operating conditions (see Note 1)

PARAMETER		MIN	TYP	MAX	UNIT
$t_{d(RS)}$	CLKOUT1 low to reset state entered			22†	ns
$t_{d(IACK)}$	CLKOUT1 to $\overline{IACK}$ valid	– 8†	0	8	ns
$t_{d(XF)}$	XF valid before falling edge of $\overline{STRB}$	Q–12			ns

timing requirements over recommended operating conditions (see Note 1)

		MIN	NOM	MAX	UNIT
$t_{su(IN)}$	$\overline{INT}$/$\overline{BIO}$/$\overline{RS}$ setup before CLKOUT1 high (see Note 6)	32			ns
$t_{h(IN)}$	$\overline{INT}$/$\overline{BIO}$/$\overline{RS}$ hold after CLKOUT1 high (see Note 6)	0			ns
$t_{w(IN)}$	$\overline{NT}$/$\overline{BIO}$ low pulse duration	$t_{c(C)}$			ns
$t_{w(RS)}$	$\overline{RS}$ low pulse duration	$3t_{c(C)}$			ns

† This parameter is not production tested.

NOTES: 1. Q = $1/4t_{c(C)}$

3. A15–A0, $\overline{PS}$, $\overline{DS}$, $\overline{IS}$, R/$\overline{W}$, and $\overline{BR}$ timings are all included in timings referenced as “address.”
4. Delays between CLKOUT1/CLKOUT2 edges and $\overline{STRB}$ edges track each other, resulting in $t_{w(SL)}$ and $t_{w(SH)}$ being 2Q with no wait states.
5. Read data access time is defined as $t_{a(A)} = t_{su(A)} + t_{w(SL)} - t_{su(D)R}$.
6. $\overline{RS}$, $\overline{INT}$, and $\overline{BIO}$ are asynchronous inputs and can occur at any time during a clock cycle. However, if the specified setup time is met, the exact sequence shown in the timing diagram will occur. $\overline{INT}$/$\overline{BIO}$ fall time must be less than 8 ns.

$\overline{HOLD}$ TIMING

switching characteristics over recommended operating conditions (see Note 1)

PARAMETER		MIN	TYP	MAX	UNIT
$t_{d(C1L-AL)}$	$\overline{HOLDA}$ low after CLKOUT1 low	0†		10	ns
$t_{dis(AL-A)}$	$\overline{HOLDA}$ low to address three-state		0		ns
$t_{dis(C1L-A)}$	Address three-state after CLKOUT1 low ($\overline{HOLD}$ mode) (see Note 7)			20†	ns
$t_{d(HH-AH)}$	$\overline{HOLD}$ high to $\overline{HOLDA}$ high			25	ns
$t_{en(A-C1L)}$	Address driven before CLKOUT1 low ($\overline{HOLD}$ mode) (see Note 7)			8†	ns

timing requirements over recommended operating conditions (see Note 1)

		MIN	NOM	MAX	UNIT
$t_{d(C2H-H)}$	$\overline{HOLD}$ valid after CLKOUT2 high			Q–24	ns

NOTES: 1. $Q = 1/4t_{c(C)}$
7. A15–A0, $\overline{PS}$, $\overline{DS}$, $\overline{IS}$, $\overline{STRB}$, and R/$\overline{W}$ timings are all included in timings referenced as “address.”

SERIAL PORT TIMING

switching characteristics over recommended operating conditions (see Note 1)

PARAMETER		MIN	TYP	MAX	UNIT
$t_{d(CH-DX)}$	DX valid after CLKX rising edge (see Note 8)			80	ns
$t_{d(FL-DX)}$	DX valid after FSX falling edge (TXM = 0) (see Note 8)			45	ns
$t_{d(CH-FS)}$	FSX valid after CLKX rising edge (TXM = 1)			45	ns

timing requirements over recommended operating conditions (see Note 1)

		MIN	NOM	MAX	UNIT
f_{sx}	Serial port frequency	1.25		5,000	kHz
$t_{c(SCK)}$	Serial port clock (CLKX/CLKR) cycle time	200		800,000	ns
$t_{w(SCK)}$	Serial port clock (CLKX/CLKR) low pulse duration (see Note 9)	80			ns
$t_{w(SCK)}$	Serial port clock (CLKX/CLKR) high pulse duration (see Note 9)	80			ns
$t_{su(FS)}$	FSX/FSR setup time before CLKX/CLKR falling edge (TXM = 0)	18			ns
$t_{h(FS)}$	FSX/FSR hold time after CLKX/CLKR falling edge (TXM = 0)	20			ns
$t_{su(DR)}$	DR setup time before CLKR falling edge	10			ns
$t_{h(DR)}$	DR hold time after CLKR falling edge	20			ns

NOTES: 1. $Q = 1/4t_{c(C)}$
8. The last occurrence of FSX falling and CLKX rising.
9. The duty cycle of the serial port clock must be within 40–60%. Serial port clock (CLKX/CLKR) rise and fall times must be less than 25 ns.

PARAMETER MEASUREMENT INFORMATION

Timing measurements are referenced to and from a low voltage of 0.8 volts and a high voltage of 2.2 volts unless otherwise noted.

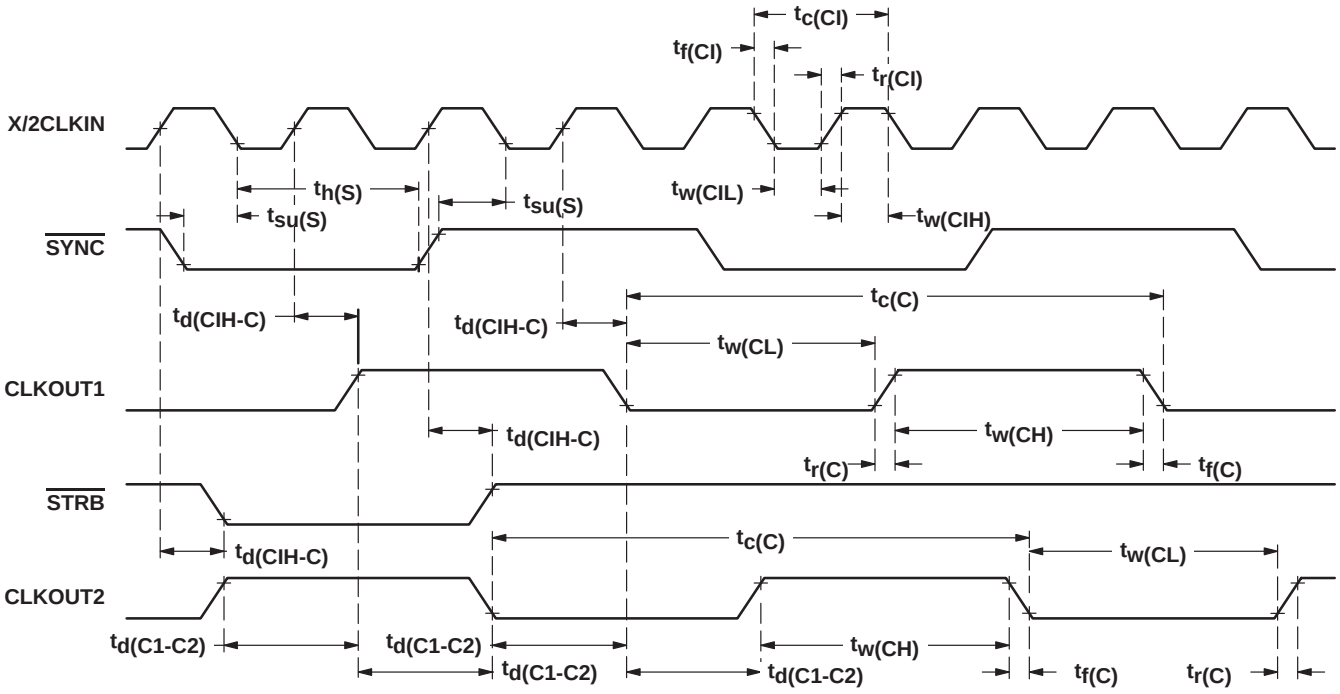


Figure 4. Clock Timing

PARAMETER MEASUREMENT INFORMATION

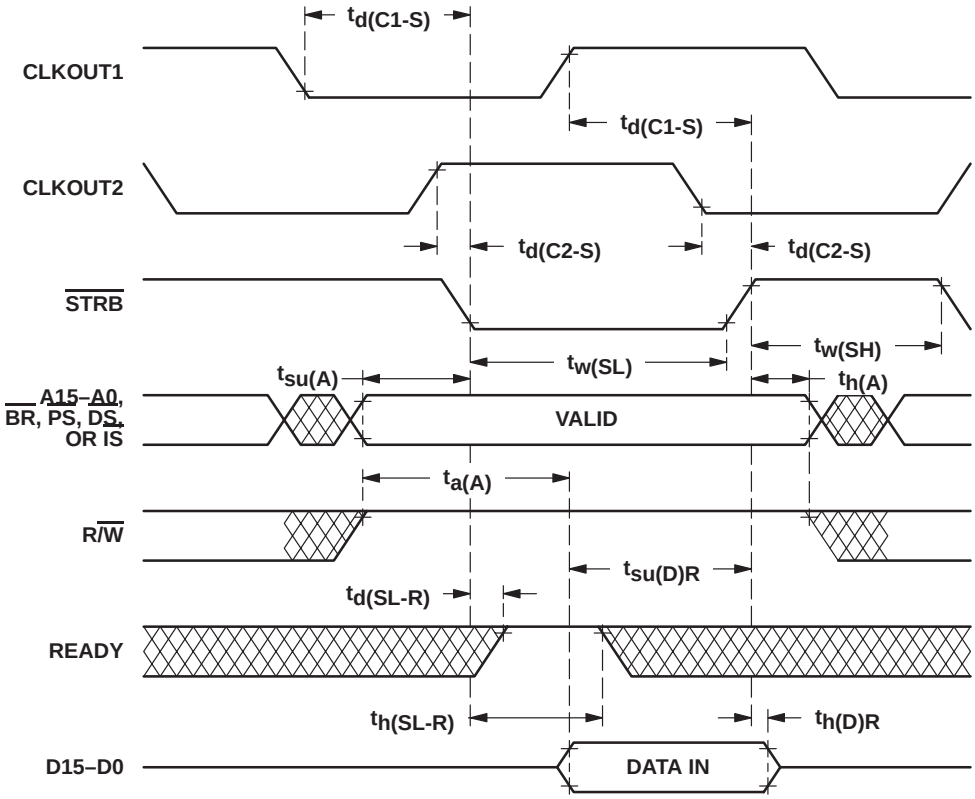


Figure 5. Memory Read Timing

PARAMETER MEASUREMENT INFORMATION

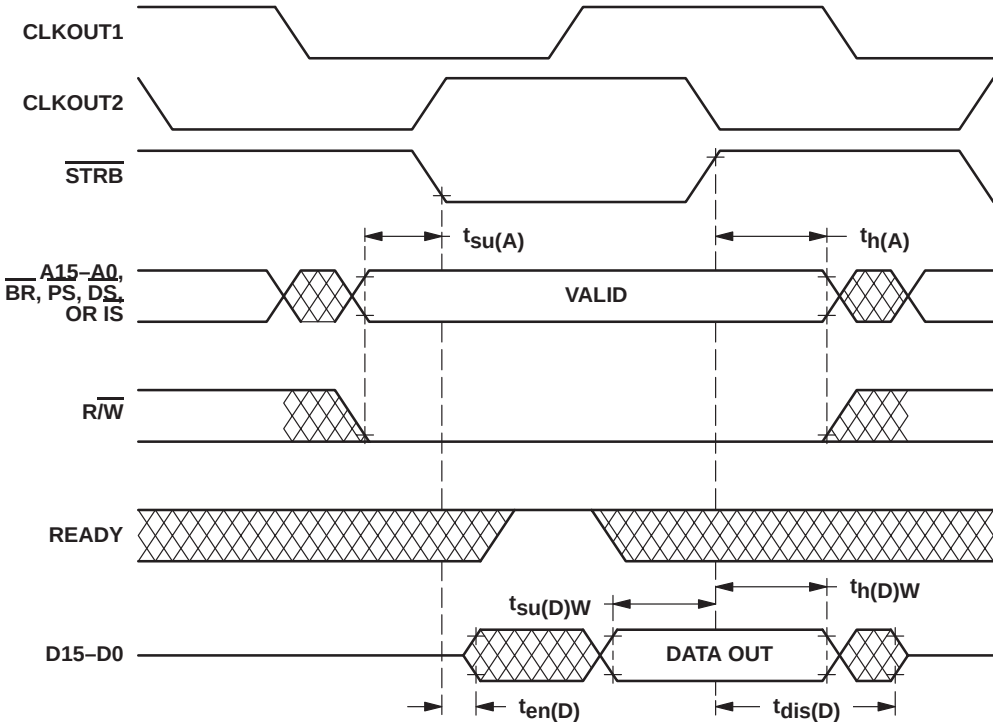


Figure 6. Memory Write Timing

PARAMETER MEASUREMENT INFORMATION

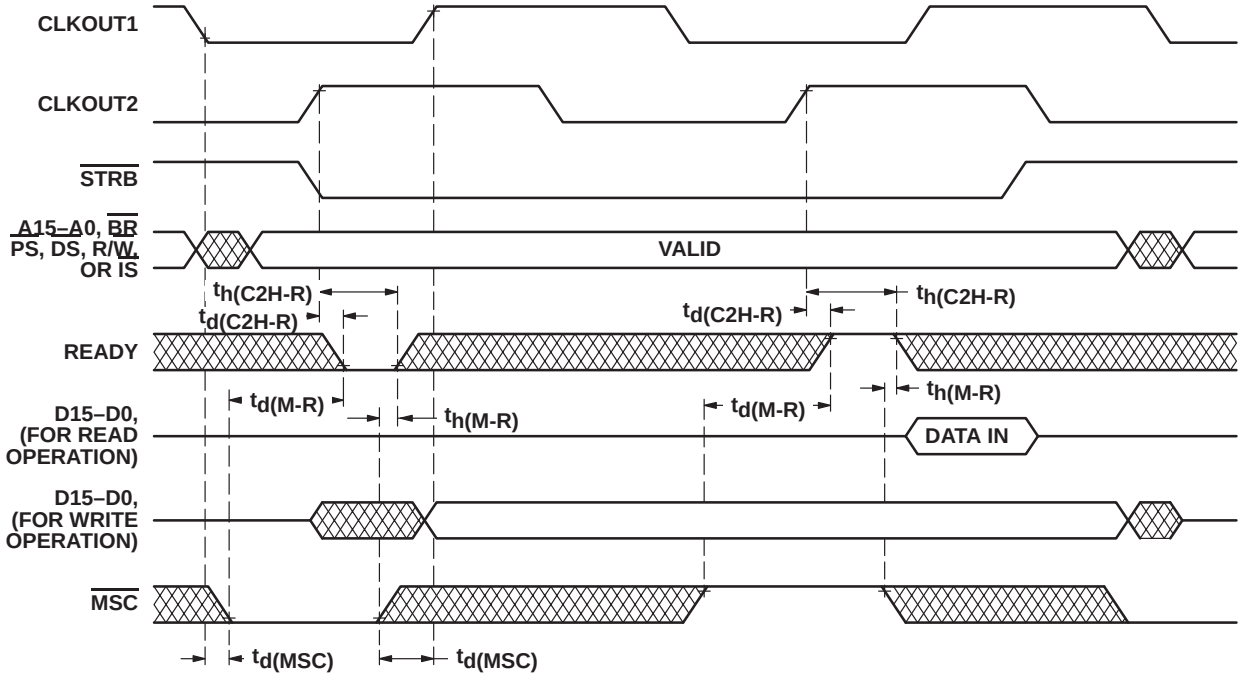
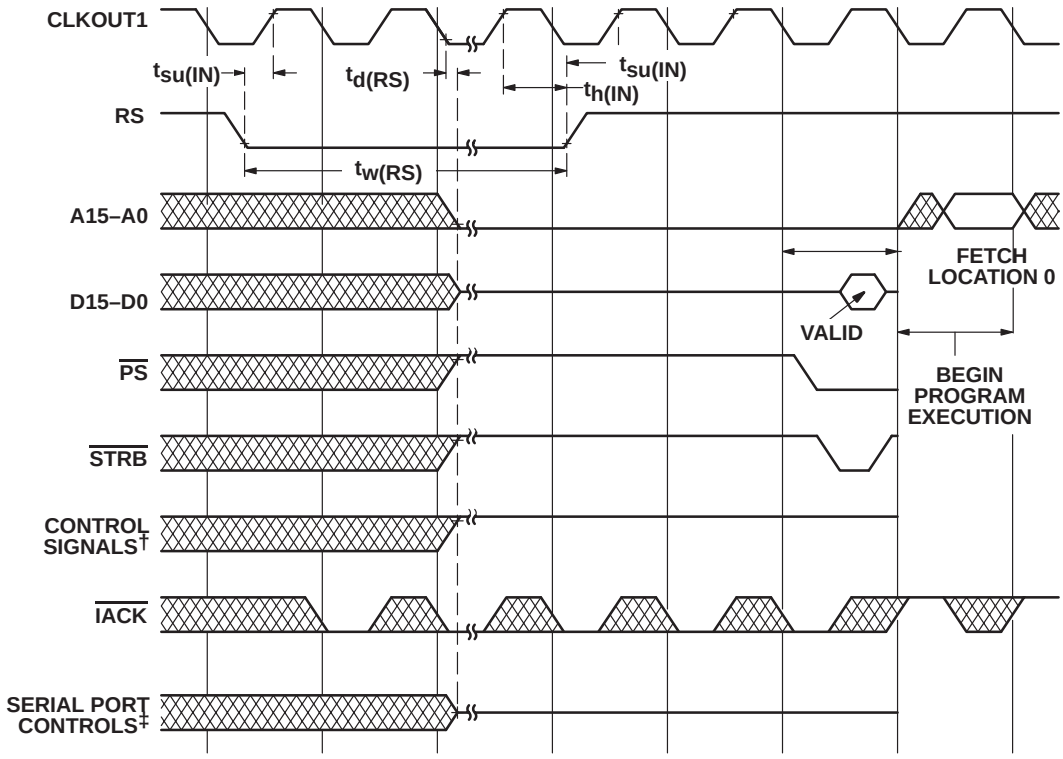


Figure 7. One Wait-State Memory Access Timing

PARAMETER MEASUREMENT INFORMATION



† Control signals are $\overline{DS}$, $\overline{IS}$, R/$\overline{W}$, and XF.
‡ Serial port controls are DX and FSX.

Figure 8. Reset Timing

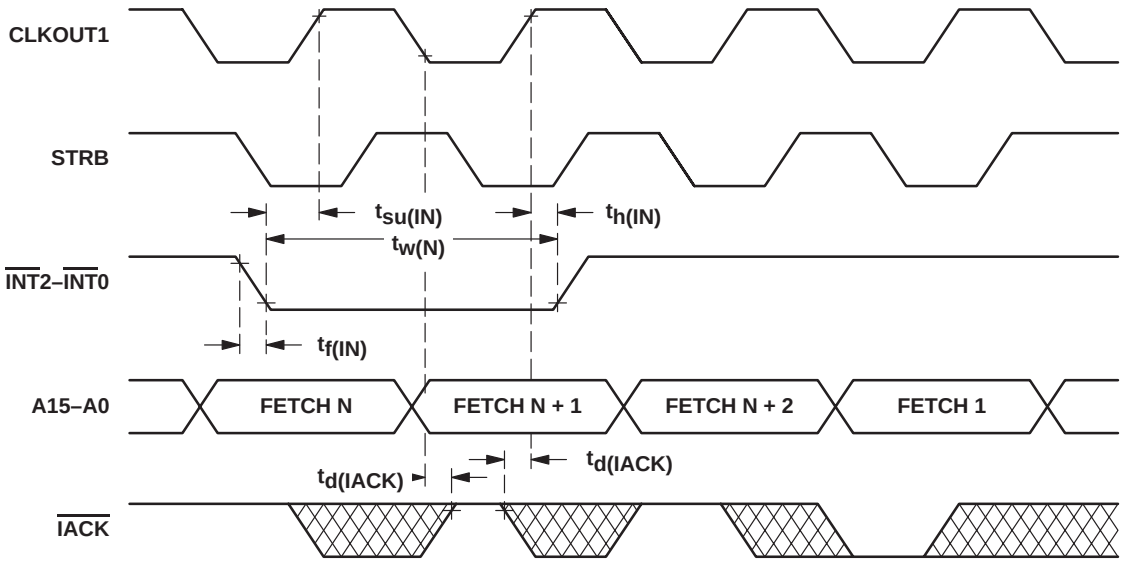


Figure 9. Interrupt Timing

PARAMETER MEASUREMENT INFORMATION

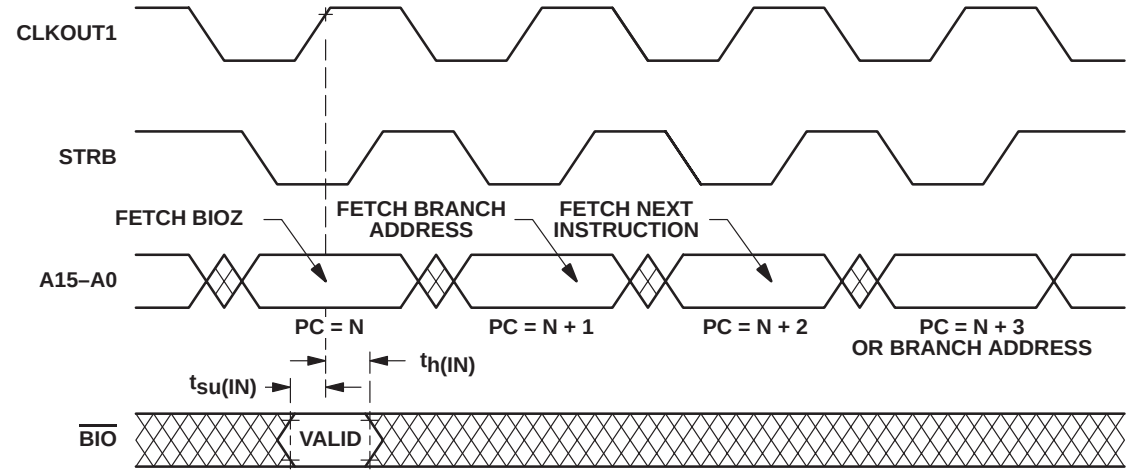


Figure 10. $\overline{BIO}$ Timing

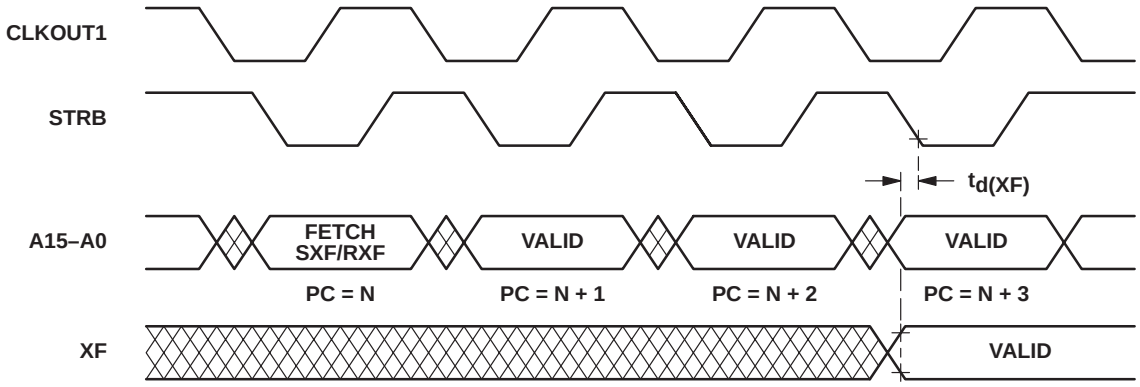
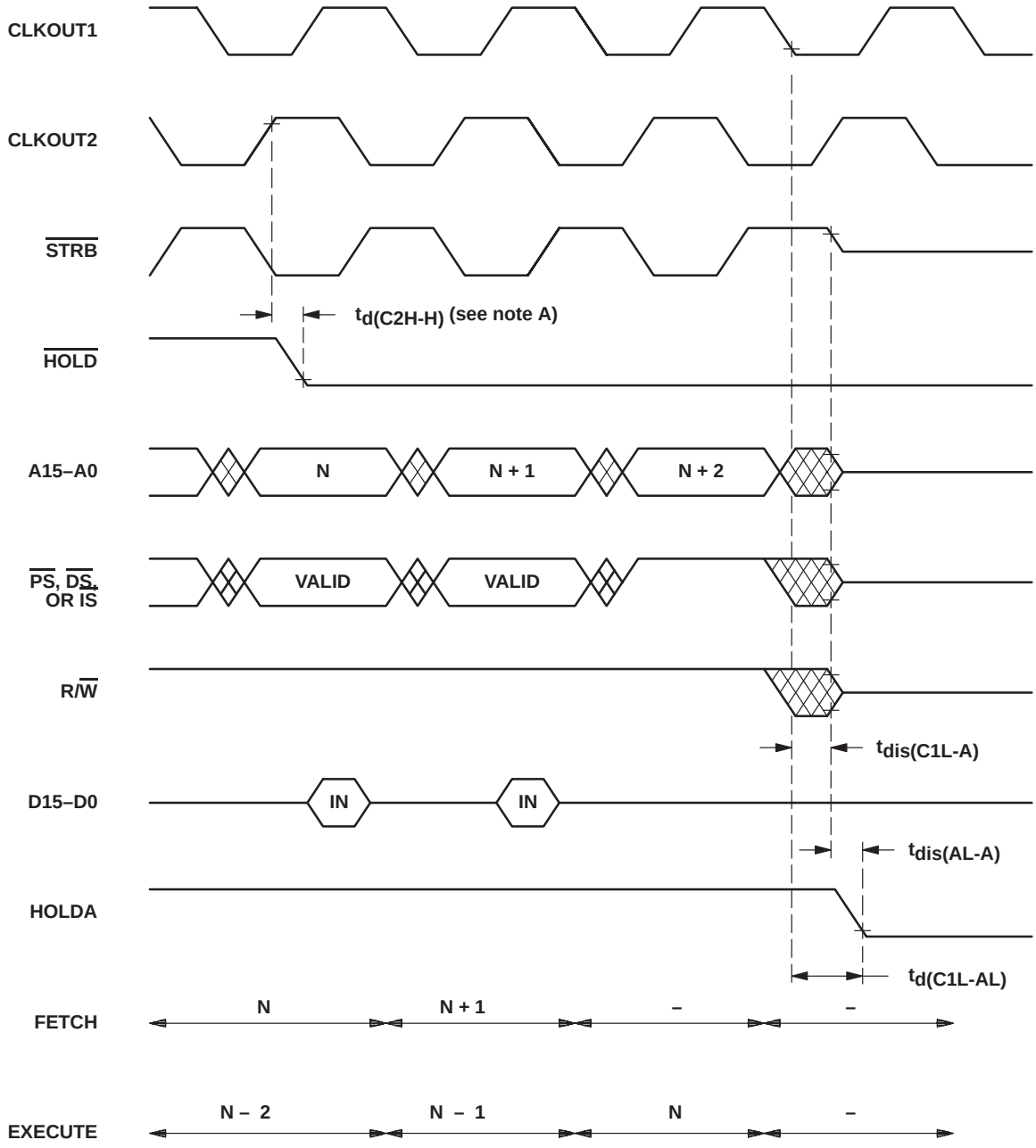


Figure 11. External Flag Timing

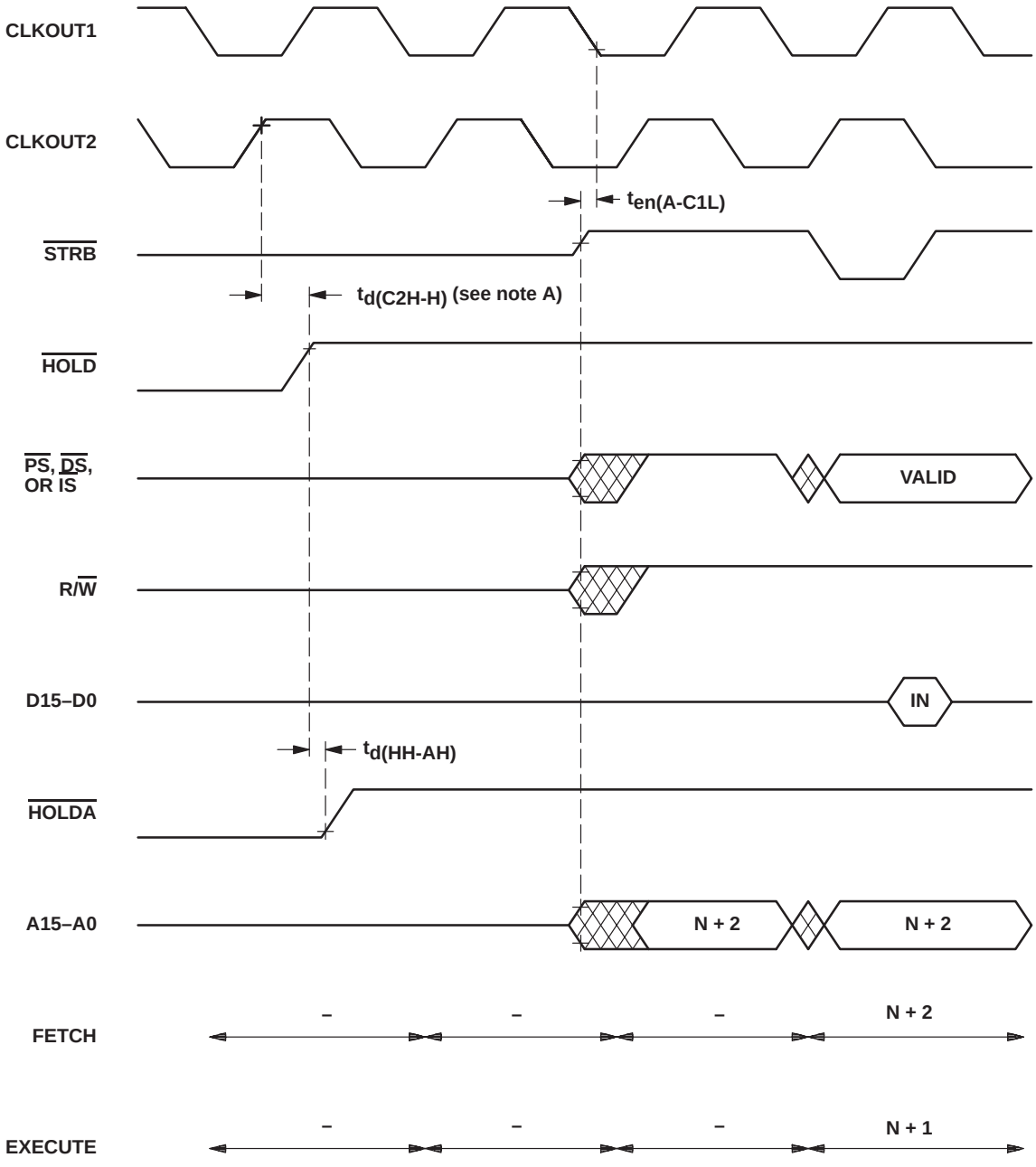
PARAMETER MEASUREMENT INFORMATION



NOTE A: HOLD is an asynchronous input that can occur at any time during a clock cycle. If the specified timing is met, the exact sequence shown will occur; otherwise, a delay of one CLKOUT2 cycle will occur.

Figure 12. HOLD Timing (Part A)

PARAMETER MEASUREMENT INFORMATION



NOTE A: HOLD is an asynchronous input that can occur at any time during a clock cycle. If the specified timing is met, the exact sequence shown will occur; otherwise, a delay of one CLKOUT2 cycle will occur.

Figure 13. HOLD Timing (Part B)

PARAMETER MEASUREMENT INFORMATION

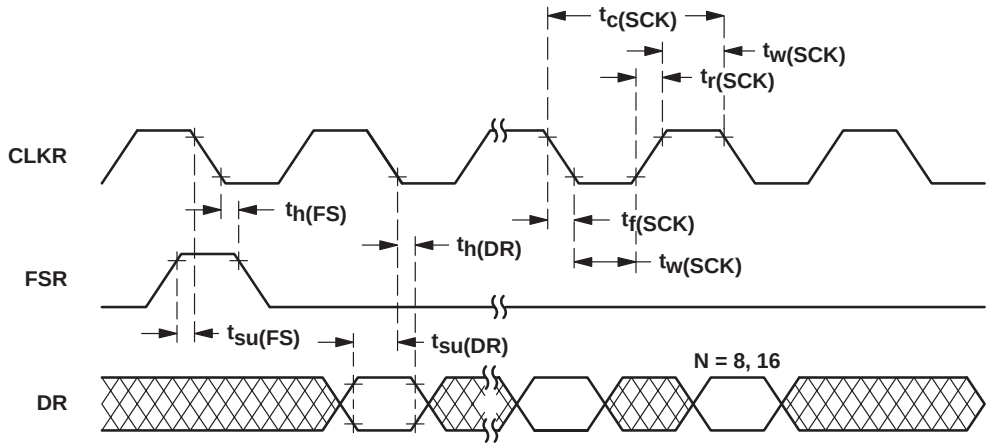


Figure 14. Serial Port Receive Timing

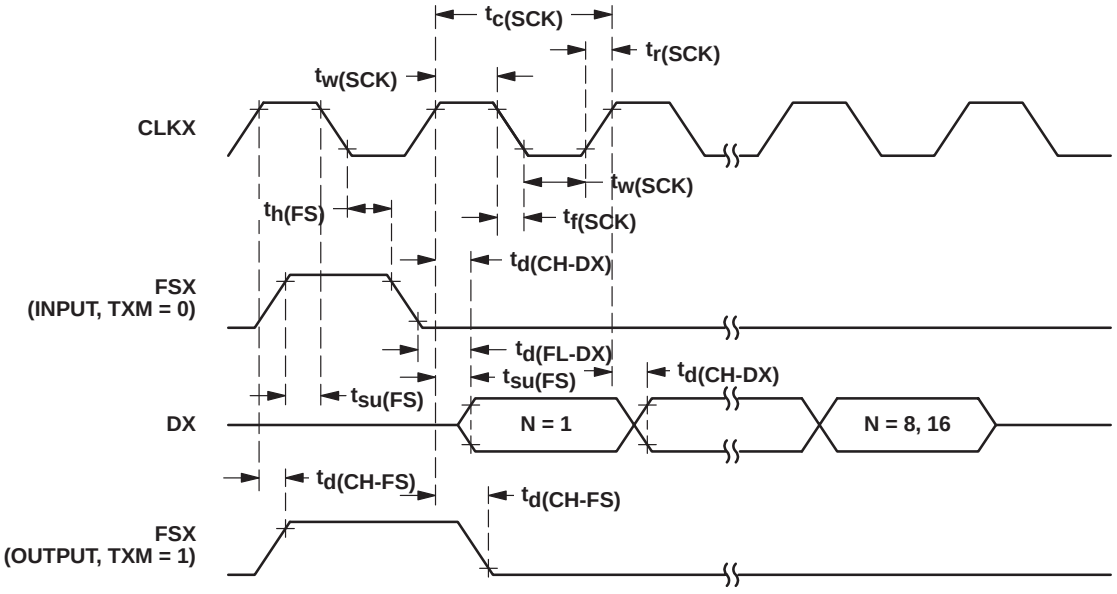
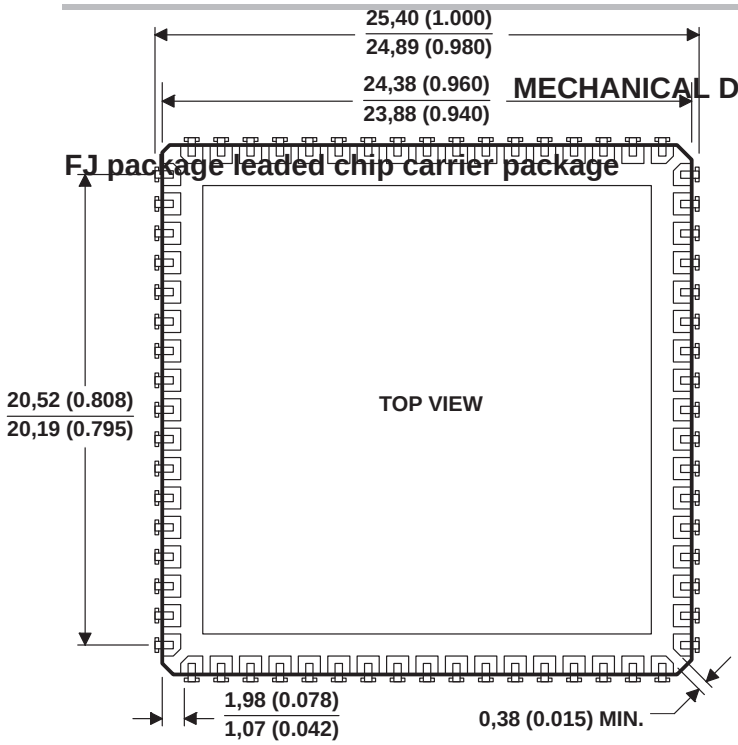


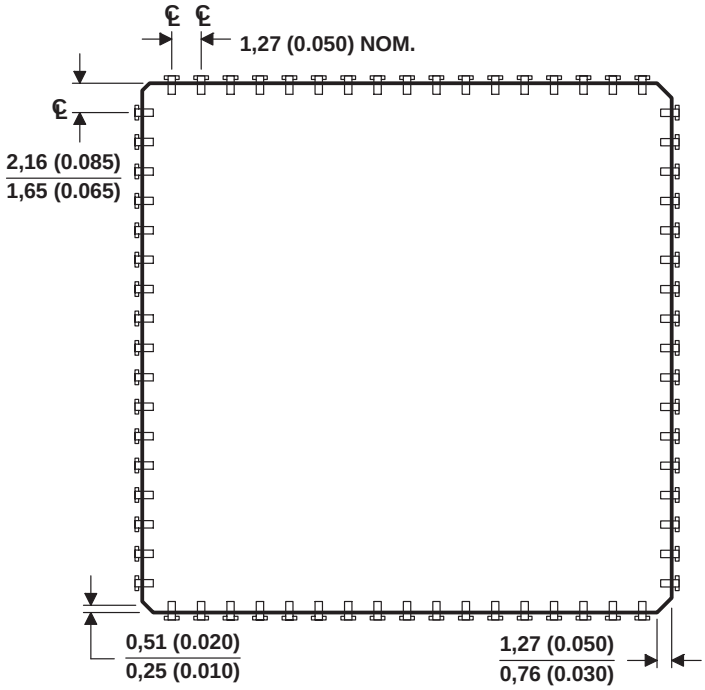
Figure 15. Serial Port Transmit Timing

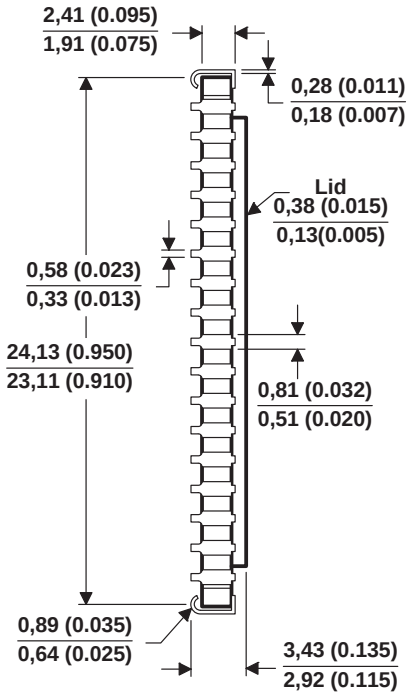
MECHANICAL DATA

FJ package leaded chip carrier package



PARAMETER		MAX	UNIT
$R_{\theta JA}$	Junction-to-free-air thermal resistance	50	°C/W
$R_{\theta JC}$	Junction-to-case thermal resistance	7	°C/W

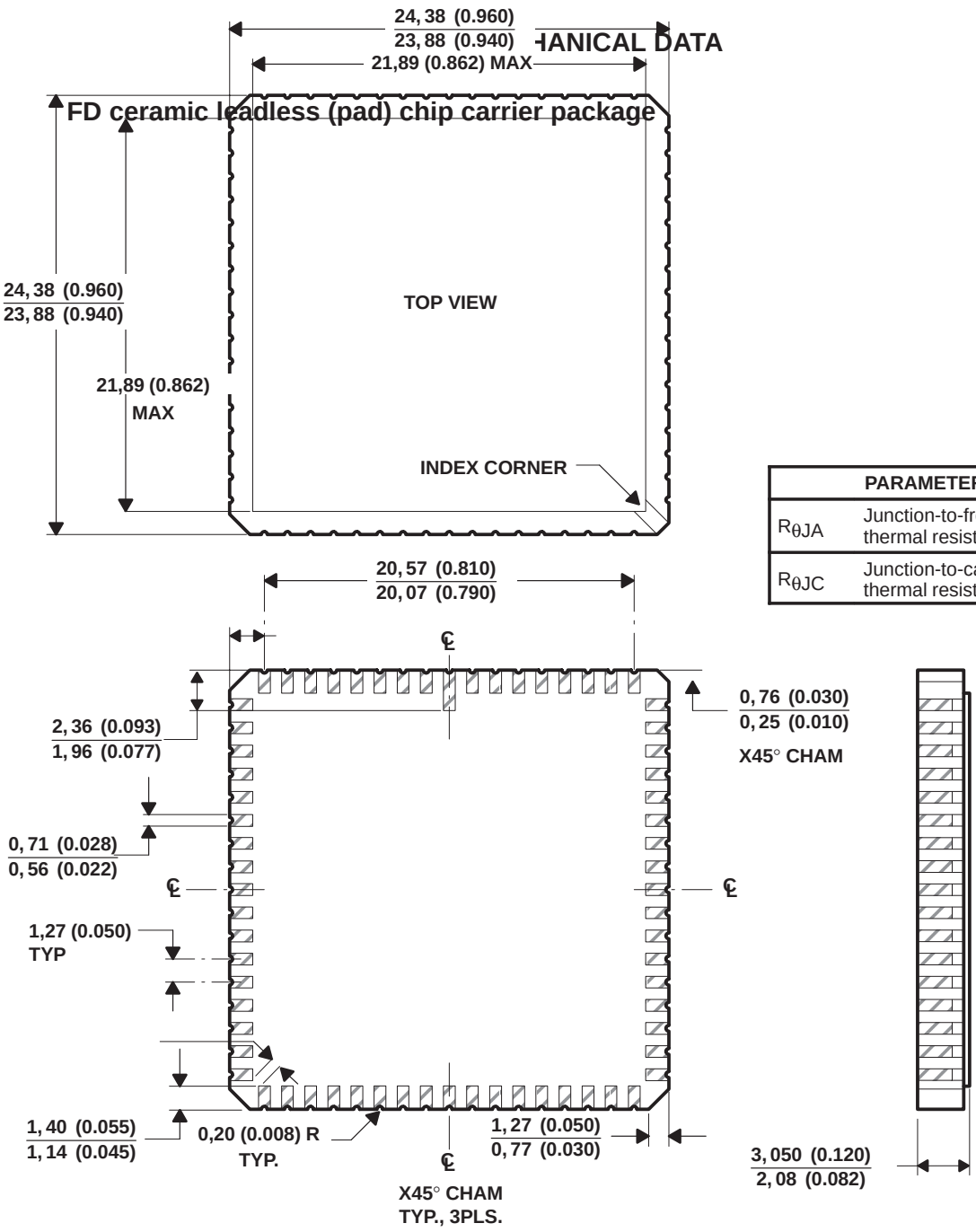




ALL DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES.

MECHANICAL DATA

FD ceramic leadless (pad) chip carrier package

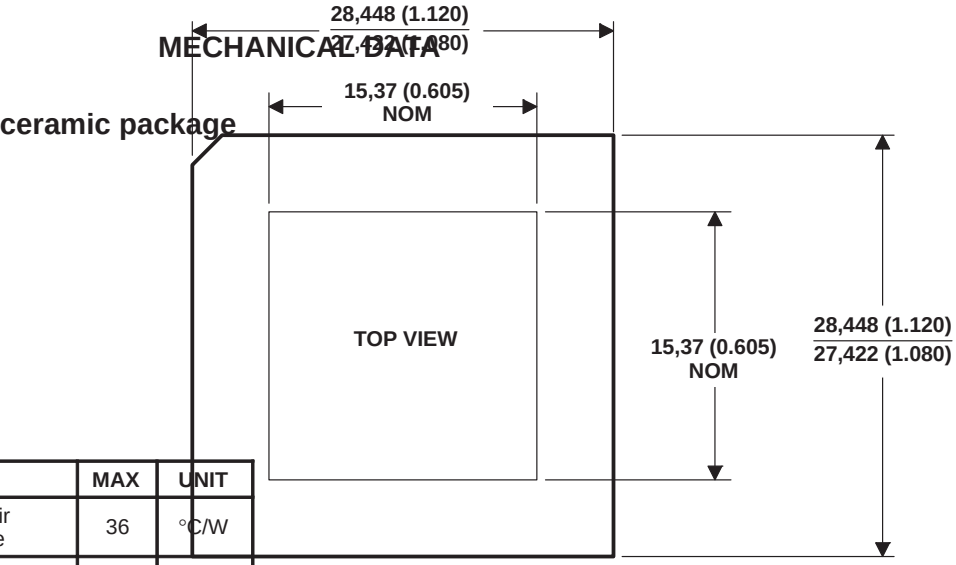


PARAMETER		MAX	UNIT
$R_{\theta JA}$	Junction-to-free-air thermal resistance	39.9	°C/W
$R_{\theta JC}$	Junction-to-case thermal resistance	7	°C/W

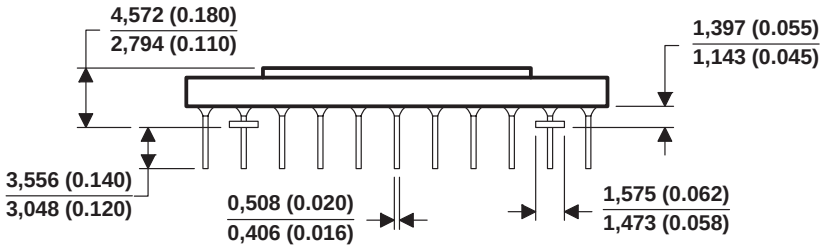
ALL DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES WITH THE INCHES GOVERNING

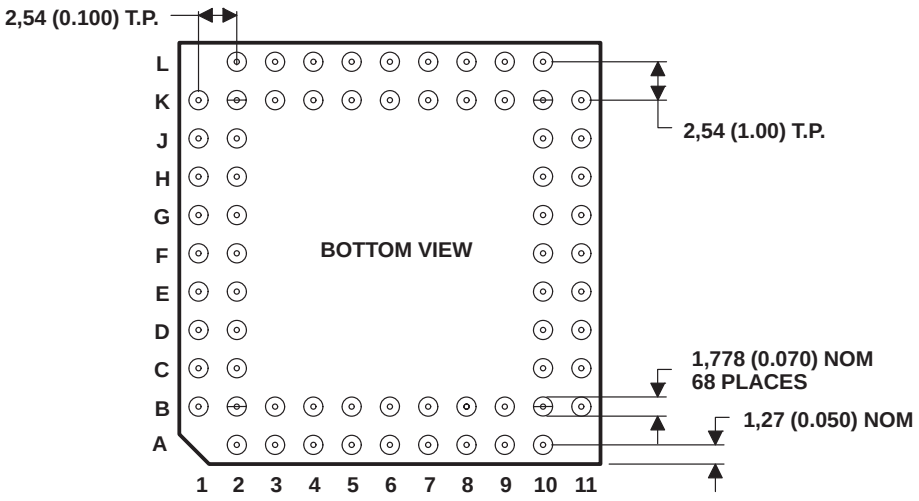
MECHANICAL DATA

68-pin GB grid array ceramic package



PARAMETER		MAX	UNIT
$R_{\theta JA}$	Junction-to-free-air thermal resistance	36	°C/W
$R_{\theta JC}$	Junction-to-case thermal resistance	6	°C/W





ALL LINEAR DIMENSIONS ARE IN MILLIMETERS AND PARENTHETICALLY IN INCHES

Appendix F

TMS320E25 EPROM Programming

This appendix describes the TMS320E25 EPROM cell. The TMS320E25 incorporates a 4K × 16-bit EPROM, which is implemented from a standard TMS27C64 EPROM cell. This expands the capabilities of the TMS320E25 in the areas of prototyping, early field testing, and production.

Key features of the EPROM cell include standard programming techniques with verification capability of all bits. The EPROM cell features an internal mechanism for security purposes. This prevents all proprietary data from being read and, thereby, protects privileged information against possible copyright violations. The mechanism also prevents the EPROM contents from being read. An adapter socket (part number TMDX3270120) provides the 68-pin to 28-pin conversion that is necessary when programming the TMS320E25. Refer to the data sheet in Appendix A.

This appendix describes erasure, programming and verification, and EPROM protection and verification. The major topics are as follows:

Topic **Page**

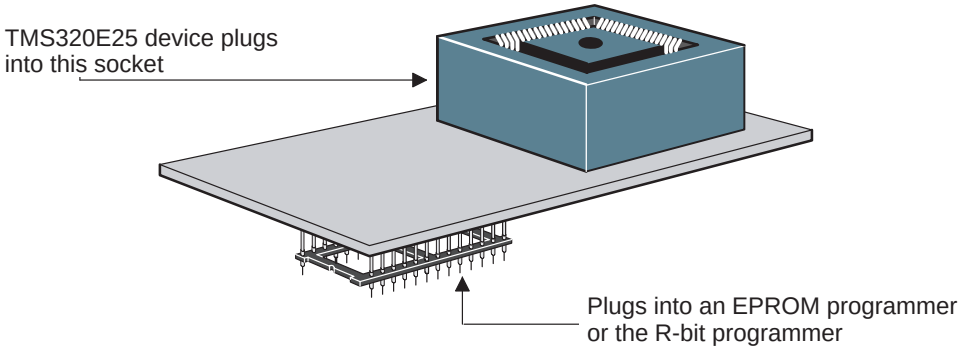
F.1	**Using the EPROM Programmer Adapter Socket**	**F-2**
F.2	**Programming and Verification**	**F-4**
F.3	**EPROM Protection and Verification**	**F-12**

F.1 Using the EPROM Programmer Adapter Socket

Most EPROM programmers have a 28-pin DIP-type socket for use with EPROM devices such as the TMS27C64. In order to use this type of programmer to program a TMS320 40-pin DIP or PLCC/CLCC, you must use a special adapter that converts the programmer socket into a socket that can accept a TMS320E25 device.

Figure F–1 shows an example of a PLCC/CLCC-type adapter socket so that you can see the socket for the device and the portion that plugs into the EPROM programmer.

Figure F–1. EPROM Programming Adapter Socket



F.1.1 Supplying External Power

The adapter socket has two sets of jumpers that indicate whether the power supply is internal (from the EPROM programmer) or external. The adapter socket is shipped from the factory with the jumpers at the internal power setting. In some cases, the EPROM programmer cannot supply the V_{CC} power needs of the TMS320E25 device, so it becomes necessary to supply external V_{CC}.

The following conditions will determine whether external power is needed.

- The TMS320E25's clock must be disabled during programming. Because the device uses a dynamic logic for much of its internal circuitry, the I_{CC} requirements for V_{CC} are significantly greater than a typical 27C64-type EPROM. As a result, many EPROM programmers sense this condition and erroneously indicate that the chip is plugged in backwards. To prevent this from occurring, a jumper connection and test point are available for an external 5-V logic supply. This effectively bypasses the EPROM programmer's I_{CC} test and allows the device to be programmed.

- Additionally, a jumper and test point are available for the V_{PP} supply. The V_{PP} signal is a pulsed signal and fully complies with the standards for a 27C64 EPROM device. This option is never needed, and the jumpers should be left in the internal position at all times.

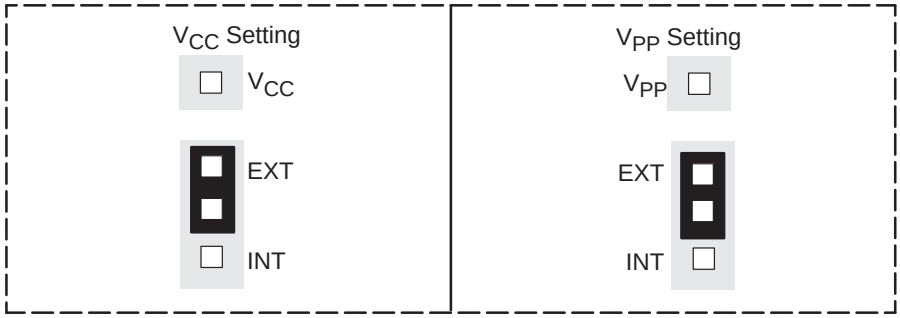
To supply external V_{CC}:

1) Find the jumper nearest the V_{CC} pin and move the jumper so that it is over the EXT and center pins.

2) Connect the external V_{CC} to the pin labeled V_{CC}.

Figure F–2 shows the jumper setting placement for internal and external power. The V_{CC} and V_{PP} pins are also shown.

Figure F–2. V_{CC} and V_{PP} Jumper Settings for External Power



CAUTION

Whenever supplying an external V_{CC}, you *must* connect a common ground lead between the power supply and the programmer adapter.

F.2 Programming and Verification

The TMS320E25 EPROM cell is similar to the TMS27C64 8K × 8-bit EPROM. Their memories can be erased by using an ultraviolet light source and electrically programmed by using the same family and device codes. The TMS320E25, like the TMS27C64, requires a 5-V supply for reading and a 12.5-V supply for programming. All programming signals are TTL level. Locations may be systematically or randomly programmed as a singular or blocked address. Unlike some EPROM cells that may require the high byte before the low byte, each byte of data must be loaded into the TMS320E25 EPROM cell with the low byte preceding the high byte (see Figure F–3). To avoid memorization of the proper order, an inverter is placed in the circuit of Figure F–4 and performs the necessary byte reversal for the TMS320E25.

Figure F–3. EPROM Programming Data Format

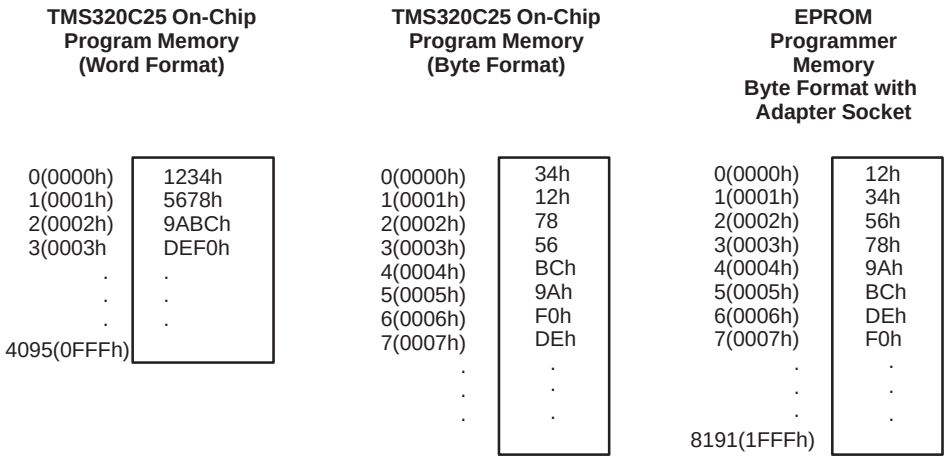


Figure F–4 shows the wiring diagram when the TMS320E25 is programmed with the TMS27C64 in its 28-pin output form. The illustration furnishes a table for each pin nomenclature on the TMS27C64 with a description of that pin. Programming the code into the device should be done in the serial mode.

Although acceptable by some EPROM programmers, the signature mode *cannot* be used on any TMS320C25 device. The signature mode will input a high-level voltage (12.5 V_{DC}) onto pin A9. Since the TMS320E25 EPROM cell is not designed for high voltage, the cell will be damaged. To prevent an accidental application of voltage, Texas Instruments has inserted a 3.9-kΩ resistor between A9 of the TI programmer socket and the programmer itself.

Figure F–4. TMS320E25 EPROM Conversion to TMS27C64 EPROM Pinout

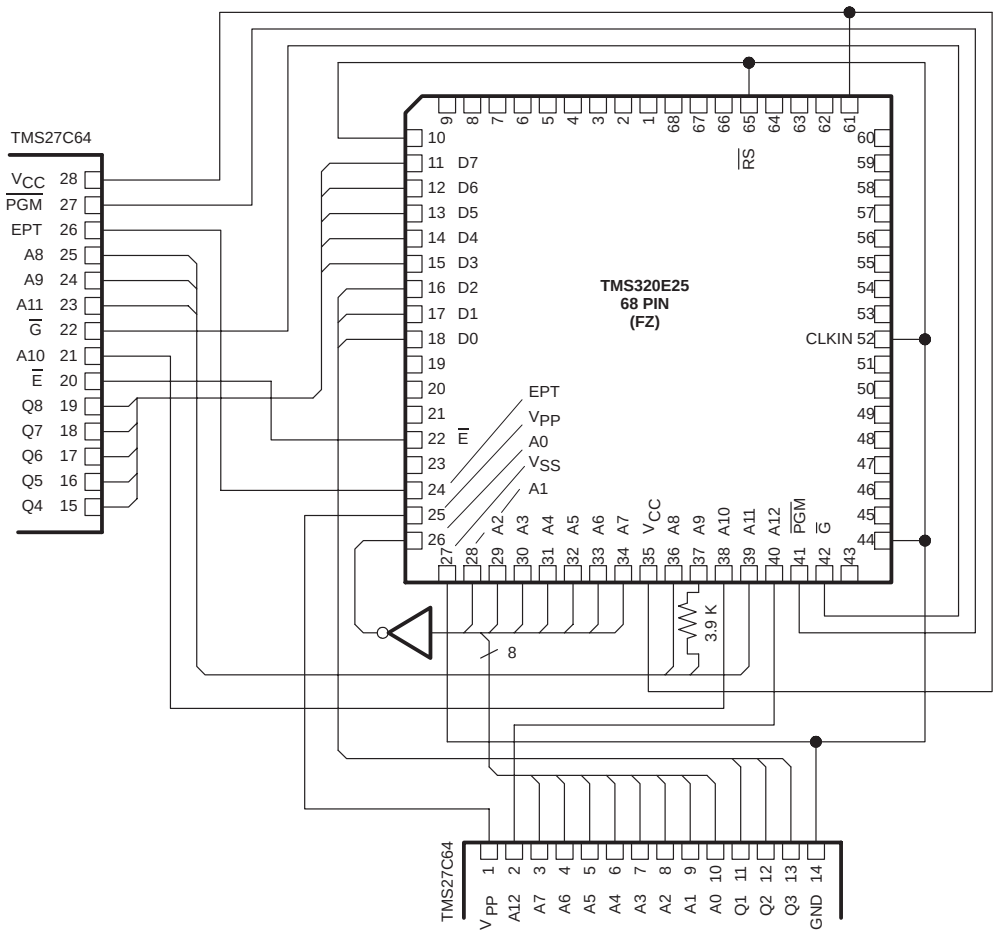


Table G–1. Pin Nomenclature (TMS320E25)

Signals	I/O	Definition
A12(MSB)–A0 (LSB)	I	On-chip EPROM programming address lines
CLKIN	I	Clock oscillator input
E	I	EPROM chip select
EPT	I	EPROM test mode select
G	I	EPROM read/verify select
GND	I	Ground
PGM	I	EPROM write/program select
Q8(MSB)–Q1(LSB)	I/O	Data lines for byte-wide programming of on-chip 8K bytes of EPROM
RS	I	Reset for initializing the device
V_{CC}	I	5-V power supply
V_{PP}	I	12.5-V power supply

Table G–2 shows the programming levels that are required when programming, verifying, and reading the EPROM cell. Following the table are individual descriptions of each programming level.

Table G–2. TMS320E25 Programming Mode Levels

Signal Name†	TMS320E25 Pin	TMS27C64 Pin	Program	Program Verify	Read	EPROM Protect	Protect Verify
$\overline{E}$	22	20	V_{IL}	V_{IL}	V_{IL}	V_{IH}	V_{IL}
$\overline{G}$	42	22	V_{IH}	$\overline{PULSE}$	$\overline{PULSE}$	V_{IH}	V_{IL}
$\overline{PGM}$	41	27	$\overline{PULSE}$	V_{IH}	V_{IH}	V_{IH}	V_{IH}
V_{PP}	25	1	V_{PP}	V_{PP}	V_{CC}	V_{PP}	V_{CC} + 1
V_{CC}	61,35	28	V_{CC} + 1	V_{CC} + 1	V_{CC}	V_{CC} + 1	V_{CC} + 1
V_{SS}	27,44,10	14	V_{SS}	V_{SS}	V_{SS}	V_{SS}	V_{SS}
CLKIN	52	14	V_{SS}	V_{SS}	V_{SS}	V_{SS}	V_{SS}
$\overline{RS}$	65	14	V_{SS}	V_{SS}	V_{SS}	V_{SS}	V_{SS}
EPT	24	26	V_{SS}	V_{SS}	V_{SS}	V_{PP}	V_{PP}
Q8–Q1	11–18	19–15,13–11	D_{IN}	Q_{OUT}	Q_{OUT}	Q_8=$\overline{PULSE}$	Q_8=RBIT
A12–A7	40–36,34	2,23,21, 24,25,3	ADDR	ADDR	ADDR	X	X
A6	33	4	ADDR	ADDR	ADDR	X	V_{IL}
A5	32	5	ADDR	ADDR	ADDR	X	X
A4	31	6	ADDR	ADDR	ADDR	V_{IH}	X
A3–A0	30–28,26	7–10	ADDR	ADDR	ADDR	X	X

LEGEND:
† =TMS320E25 EPROM programming mode produces these TMS27C64 signals.
V_{IH} = TTL high level
V_{IL} = TTL low level
ADDR = byte address bit
V_{PP} = 12.5 ± 0.25 V (FAST) or 13 ± 0.25 V (SNAP!)
V_{CC} = 5 ± 0.25 V
V_{CC} + 1 = 6 ± 0.25 V (FAST) or 6.5 V ± 0.25 V (SNAP!)
X = don't care
$\overline{PULSE}$ = low-going TTL pulse
D_{IN} = byte to be programmed at ADDR
Q_{OUT} = byte stored at ADDR

F.2.1 Erasure

Before programming, the memory must be erased by exposing high-intensity ultraviolet light (wavelength = 2537 angstroms) into the chip through its transparent lid. Note that normal ambient light contains the correct wavelength for erasure. Therefore, the window should be covered with an opaque label after programming the TMS320E25. The recommended minimum exposure dose (UV intensity × exposure time) is 15 watt-seconds per square centimeter. If located about 2.5 centimeters above the transparent lid, a typical filterless UV lamp with a 12-milliwatt-per-square-centimeter output will erase the memory in 21 minutes. After the memory is erased, all bits are in a high state.

F.2.2 FAST Programming

After erasure, all memory bits in the cell are a logic one. Logic zeros *must* now be programmed into their desired location. The FAST programming algorithm, shown in Figure F–5, is normally used to program the entire EPROM contents, although individual locations may be programmed separately. A programmed logic zero can be erased only by ultraviolet light. Data is presented in parallel (eight bits) from pins D7–D0 of the TMS320E25 to pins Q8–Q1 of the TMS27C64. Once addresses and data are stable, $\overline{PGM}$ is pulsed. The programming mode is achieved when V_{PP} = 12.5 V, $\overline{PGM} = V_{IL}$, V_{CC} = 6.0 V, $\overline{G} = V_{IH}$, and $\overline{E} = V_{IL}$. More than one TMS320E25 can be programmed if these devices are connected in parallel with each other. Locations can be programmed in any order.

FAST programming uses two types of programming pulses: prime and final. The length of the prime pulse is 1 ms. After each prime pulse, the byte being programmed is verified. If correct data is read, the final programming pulse is applied; if correct data is not read, an additional 1-ms prime pulse is applied up to a maximum of 25 times. The final programming pulse is 3x times the number of prime programming pulses applied. This sequence of programming and verifying is performed at V_{CC} = 6.0 V, and V_{PP} = 12.5 V. When the full FAST programming routine has been completed, all bits are verified with $V_{CC} = V_{PP}$ = 5 V.

F.2.3 SNAP! Pulse Programming

The EPROM can be programmed by using the TI SNAP! pulse programming algorithm; as illustrated in the flowchart of Figure F–6, programming time is greatly reduced to a nominal duration of one second. Actual programming time varies as a function of the programmer that is being used. Data is presented in parallel (eight bits) on pins Q8 through Q1. Once addresses and data are stable, $\overline{PGM}$ is pulsed.

The SNAP! pulse programming algorithm uses pulses of 100 microseconds, followed by a byte verification to determine if the addressed byte has been successfully programmed. Up to ten 100-microsecond pulses per byte are verified before a failure is recognized.

The programming mode is achieved when V_{PP} = 13.0 V, V_{CC} = 6.5 V, and $\overline{G}$ = V_{IH}, and $\overline{E}$ = V_{IL}. More than one TMS320E25 can be programmed by connecting the devices in parallel with each other. Locations may be programmed in any order. When the SNAP! pulse programming routine has been completed, all bits are verified with V_{CC} = V_{PP} = 5 V.

F.2.4 Program Verify

Programmed bits may be verified with V_{PP} = 12.5 V when $\overline{G}$ = V_{IL}, $\overline{E}$ = V_{IL}, and $\overline{PGM}$ = V_{IH}. Figure F–7 shows the timing of the program and verification operations for both FAST and SNAP! pulse programming.

Figure F–5. FAST Programming Flowchart

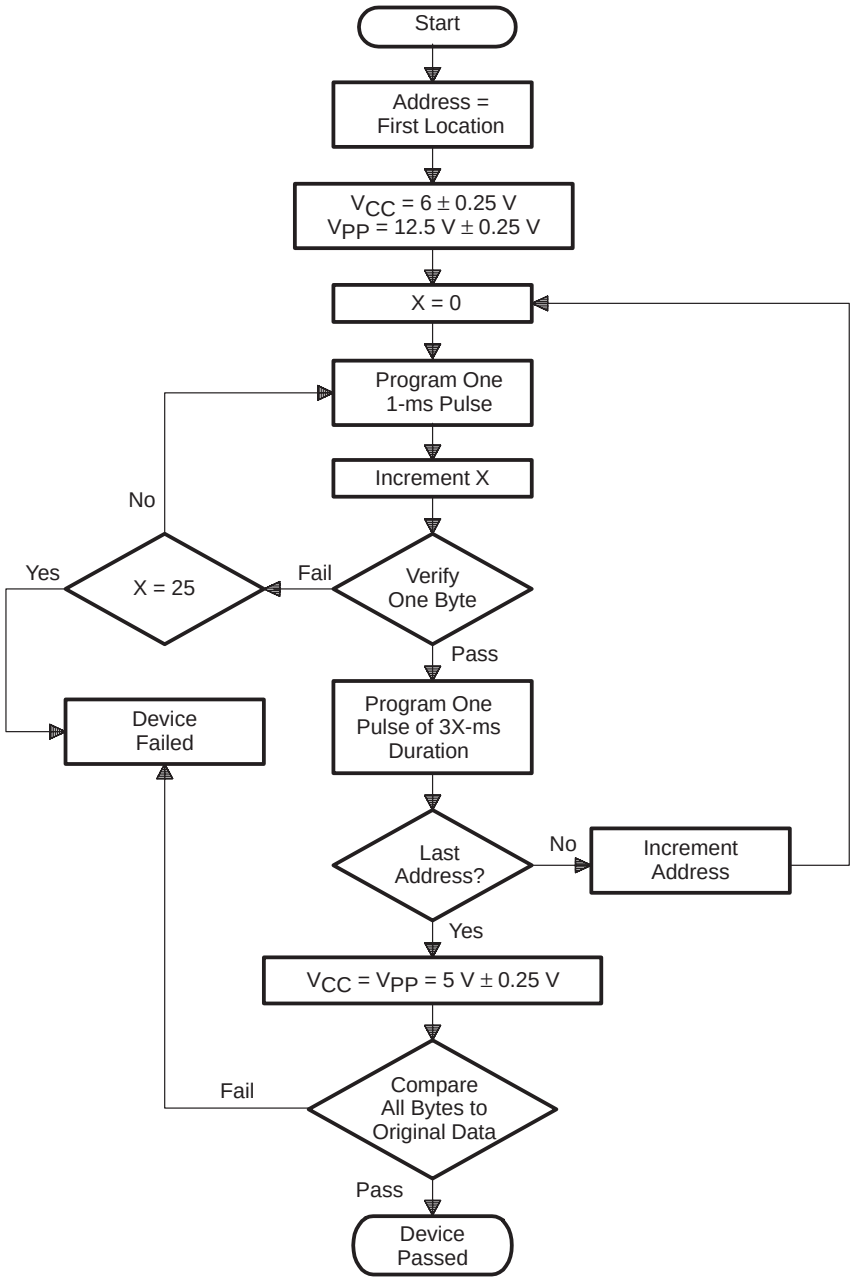


Figure F–6. SNAP! Pulse Programming Flowchart

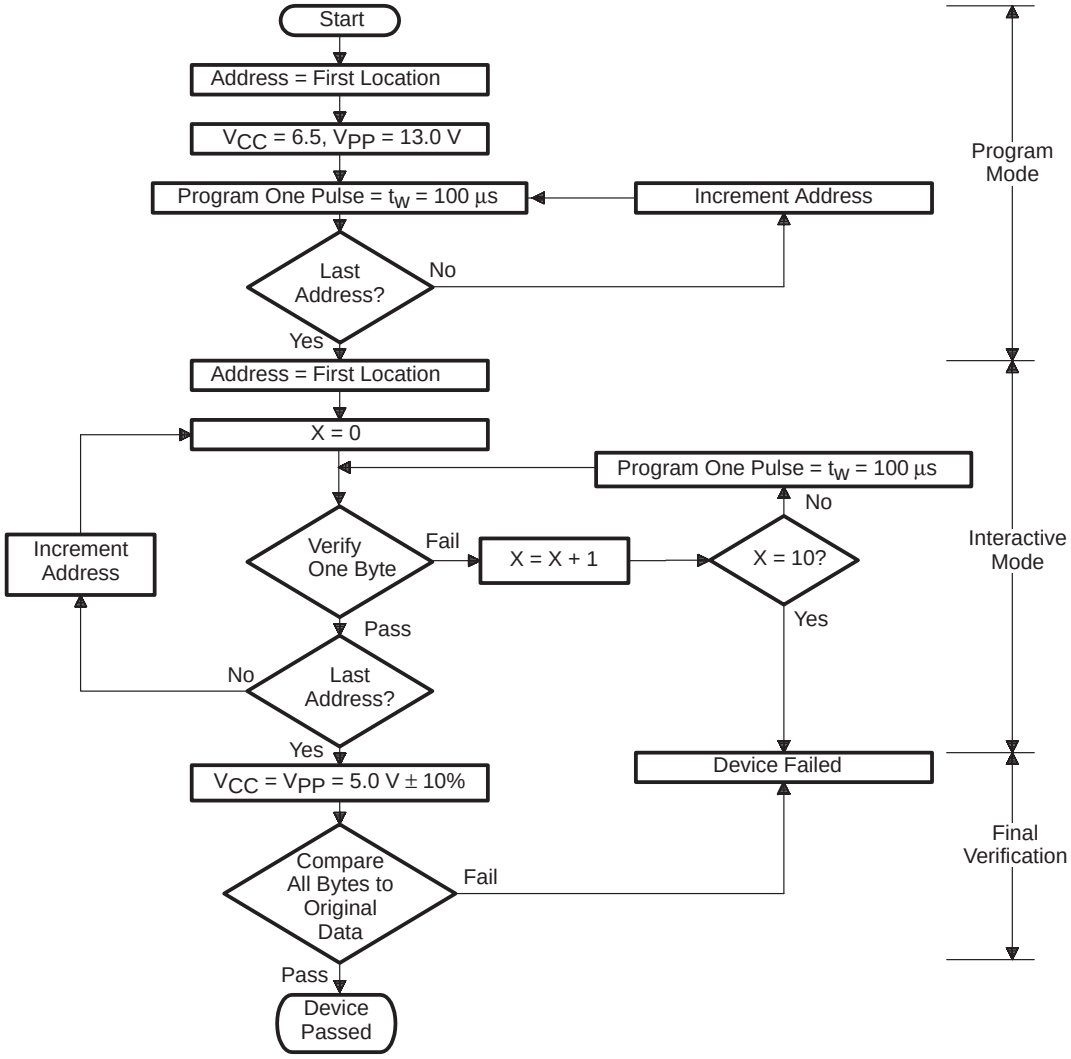
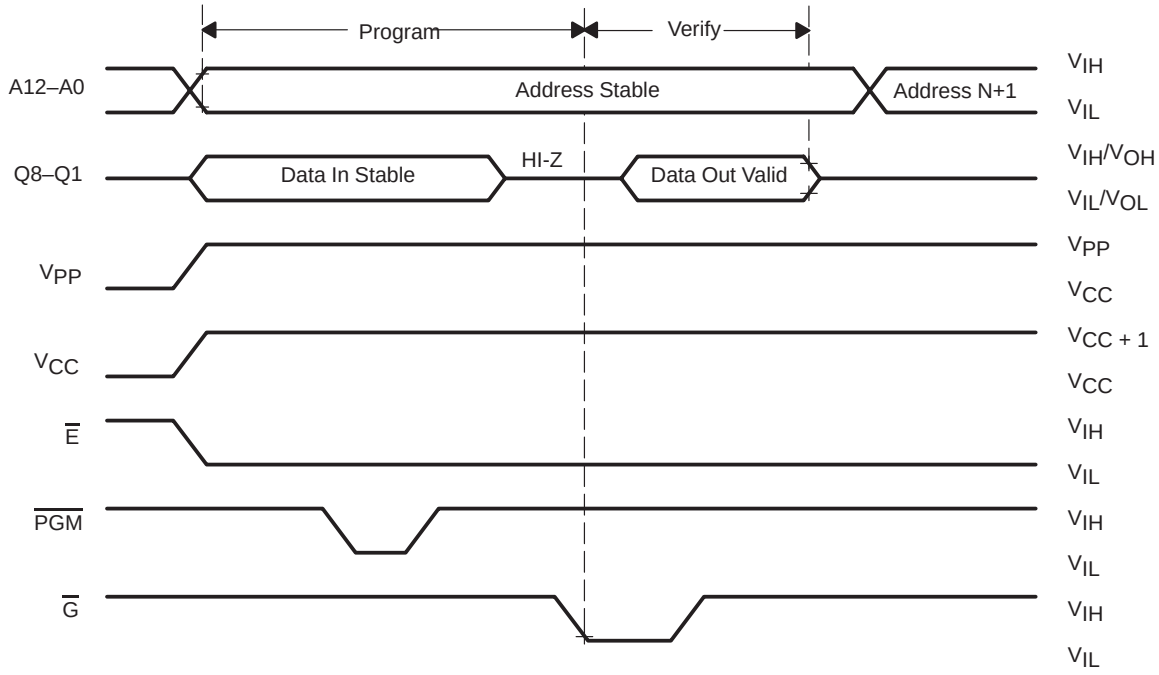


Figure F–7. Programming Timing



F.2.5 Program Inhibit

Programming can be inhibited by maintaining a high-level input on the $\overline{E}$ pin or $\overline{PGM}$ pin.

F.2.6 Read

The EPROM contents can be read outside of the programming cycle if the RBIT (ROM protect bit) has not been programmed. The read mode is accomplished by setting $\overline{E}$ to zero and pulsing G low. The contents of the EPROM location, selected by the value on the address inputs, appear on D7–D0.

F.2.7 Output Disable

During the EPROM programming process, the EPROM data outputs can be disabled, if desired, by setting the output disable mode. Depending upon the application, the output disable mode can be selected by setting either the G or the $\overline{E}$ pin on the TMS320E25 high. The selection of the pin determines the duration for which the outputs, pins Q8–Q1, of the TMS27C64 are in the high-impedance state. During this mode, pins D7–D0 on the TMS320E25 are in the high-impedance state.

F.3 EPROM Protection and Verification

This section describes the code protection feature of the EPROM cell; an internal mechanism protects the customer's code from being illegally copied by its competitors. Table G–3 shows the programming levels required for protecting the EPROM contents and verifying that protection. Following the table, individual paragraphs describe the function of the protect and verify modes.

Table G–3. TMS320E25 EPROM Protect and Protect Verify Mode Levels

SIGNAL†	TMS320E25 PIN	TMS27C64 PIN	EPROM PROTECT	PROTECT VERIFY
$\overline{E}$	22	20	V_{IH}	V_{IL}
$\overline{G}$	42	22	V_{IH}	V_{IL}
$\overline{PGM}$	41	27	V_{IH}	V_{IH}
V_{PP}	25	1	V_{PP}	V_{CC} + 1
V_{CC}	61,35	28	V_{CC} + 1	V_{CC} + 1
V_{SS}	27,44,10	14	V_{SS}	V_{SS}
CLKIN	52	14	V_{SS}	V_{SS}
$\overline{RS}$	65	14	V_{SS}	V_{SS}
EPT	24	26	V_{PP}	V_{PP}
Q8–Q1	11–18	9–15,13–11	Q8=$\overline{PULSE}$	Q8=RBIT
A12–A10	40–38	2,23,21	X	X
A9–A7	37,36,34	24,25,3	X	X
A6	33	4	X	V_{IL}
A5	32	5	X	X
A4	31	6	V_{IH}	X
A3–A0	30–28,26	7–10	X	X

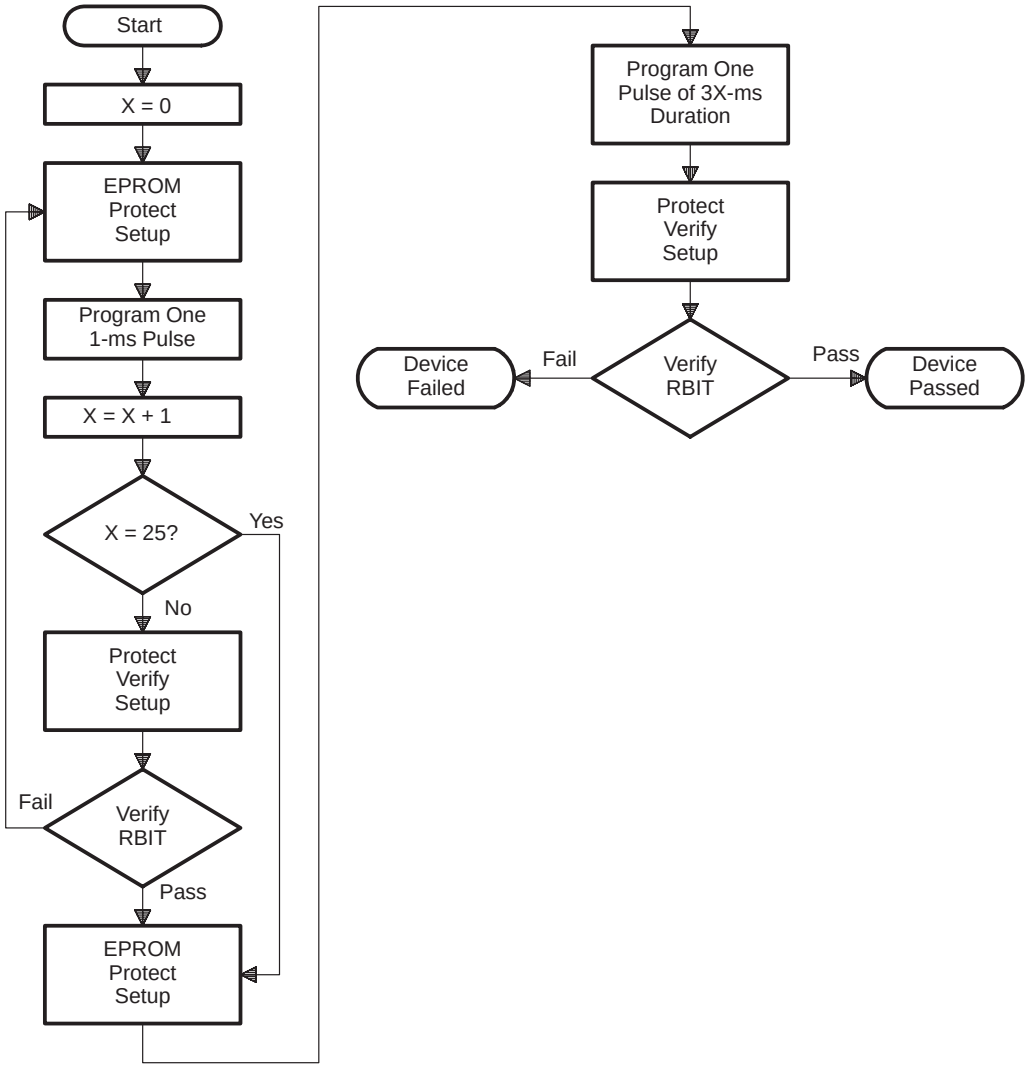
LEGEND:
† = Signal names are in accordance with TMS27C64.
V_{IH} = TTL high level; V_{IL} = low-level TTL; V_{CC} = 5 ± 0.25 V; V_{PP} = 12.5± 0.25 V (FAST); or 13 ± 0.25 V (SNAP!); V_{CC} + 1 = 6 ± 0.25 V (FAST) or 6.5 ± 0.25 V (SNAP!);
X = don't care; $\overline{PULSE}$ = low-going TTL level pulse; RBIT = ROM protect bit

F.3.1 EPROM Protection

The EPROM protection mechanism is used to prevent an intentional or accidental reading of the memory contents; this guarantees security of all proprietary algorithms. This special feature is implemented by a unique EPROM cell called the RBIT (ROM protect bit) cell. Once the contents are programmed into the EPROM, the RBIT can be programmed, this prevents access to the EPROM contents and disables the microprocessor mode. Once programmed, the RBIT can be disabled only by erasing the entire EPROM array with ultravio-

let light, thereby maintaining security of all proprietary algorithms. Programming of the RBIT is accomplished by the EPROM protection cycle, which consists of setting the $\overline{E}$, $\overline{G}$, $\overline{PGM}$, and A4 pins to a high level, applying 12.5 ± 0.25 V to both V_{PP} and EPT, and pulsing the Q8 pin to a low level. The complete sequence of operations for programming the RBIT is shown in the flowchart of Figure F–8. The required setups in the figure are detailed in Table G–3. For more detailed information about how the RBIT works, see
subsection F.3.2.

Figure F–8. EPROM Protection Flowchart

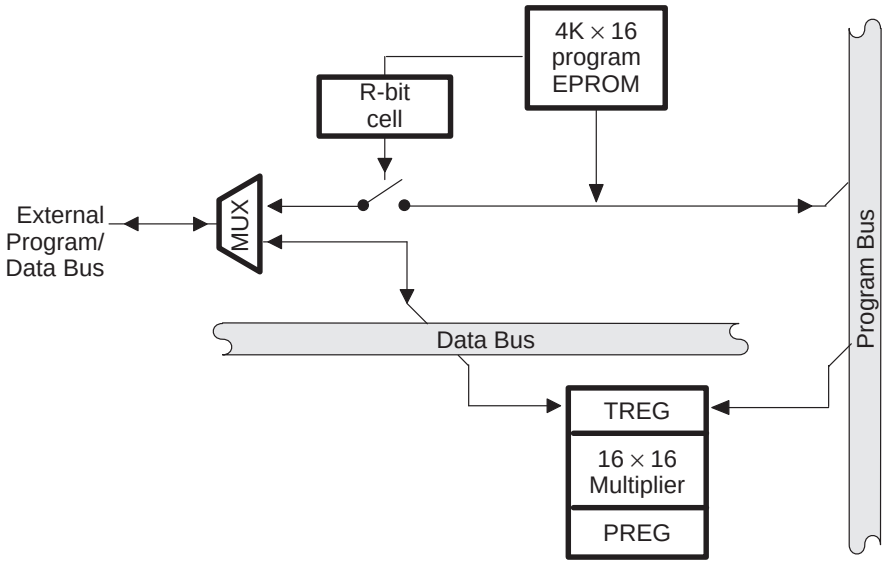


F.3.2 How the RBIT Works

When enabled, the RBIT disconnects the internal program memory bus (PBUS) from the MUX that combines the internal data bus (DBUS) to create the external program/data bus. This disconnect takes place at the MUX. For the TMS320E25, the internal nodes are left floating.

Figure F–9 shows a portion of the TMS320C2x block diagram and includes the RBIT to show how it disconnects the external and internal program spaces.

Figure F–9. How the RBIT Fits Into the TMS320E25 Block Diagrams



Programming the RBIT has some side effects that may, at first, give the appearance that the device isn't operating properly. However, because enabling the RBIT protects the EPROM space, this is normal operation. These side effects include:

- **Instructions.** Some instructions that use the external program space for storage will not operate in the same manner when the RBIT is set.

  For example, on the TMS320E25, TBLW, BLKP, and similar commands may seem to work when used to transfer external program memory to the internal data space connected to DBUS. However, a transfer from the internal program space to the external bus will not work. This happens because the RBIT feature is protecting this memory space.

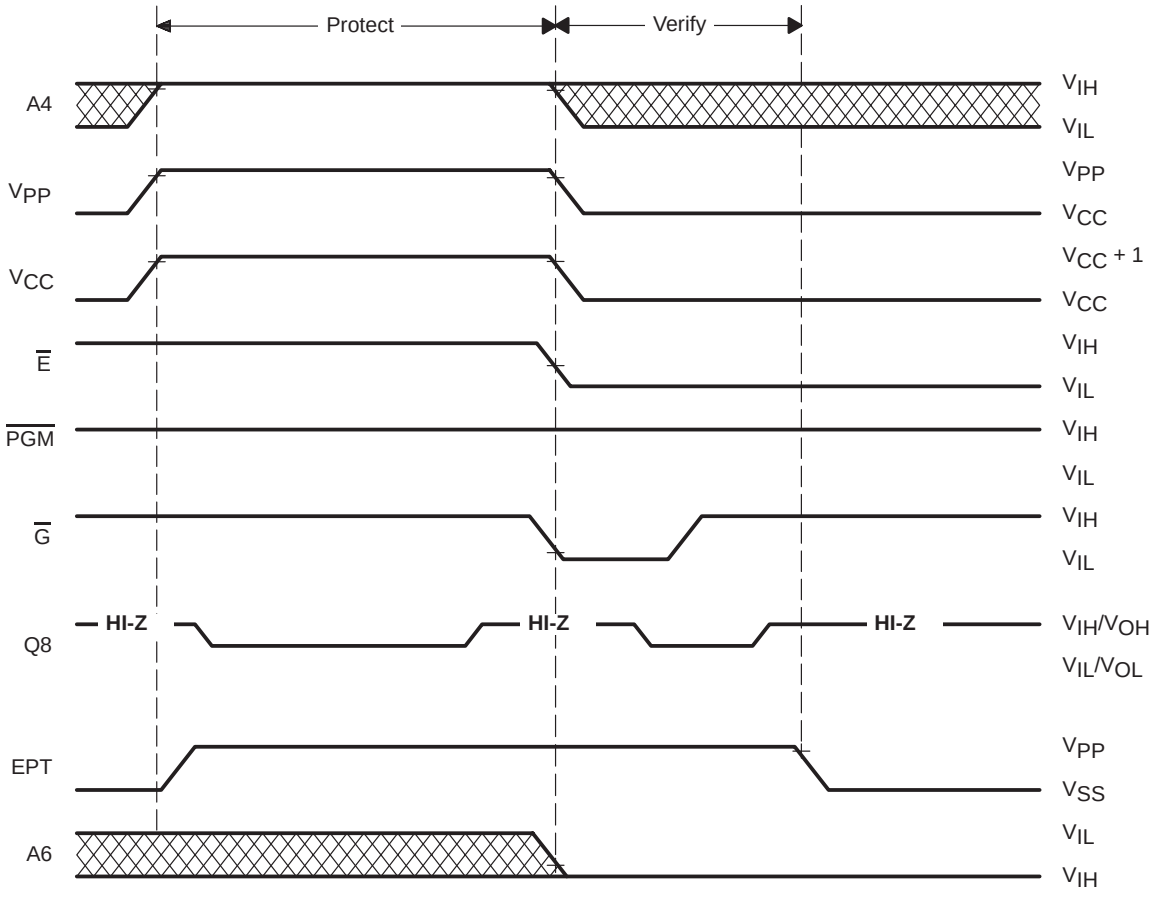
  Similarly, the MAC instruction cannot read tables stored in external program space. In this case, the data and program must be swapped, sacrificing one cycle per repeated instruction.

- **Invalid microprocessor mode.** Microprocessor mode can't be used after enabling the RBIT, because the PBUS is disconnected from the external program space.

F.3.3 Protect Verify

Following the EPROM protect mode, the protect verify mode reviews and verifies the programming of the RBIT (see Figure F–8) for accuracy. When using this mode, D7 outputs the state of the RBIT. When RBIT = 1, the EPROM is unprotected; when RBIT = 0, the EPROM is protected. The EPROM protection and verification timings are shown in Figure F–10.

Figure F–10. EPROM Protection Timing



† 12.5 V = V_{PP} and 6.0 V = V_{CC} for FAST Programming; for SNAP! Programming, 13.0 V = V_{PP} and 6.5 V = V_{CC}.

Appendix G

Analog Interface Peripherals and Applications

Texas Instruments offers many products for total system solutions, including memory options, data acquisition, and analog input/output devices. This appendix describes a variety of devices that interface directly to the TMS320 DSPs in rapidly expanding applications.

Topic **Page**

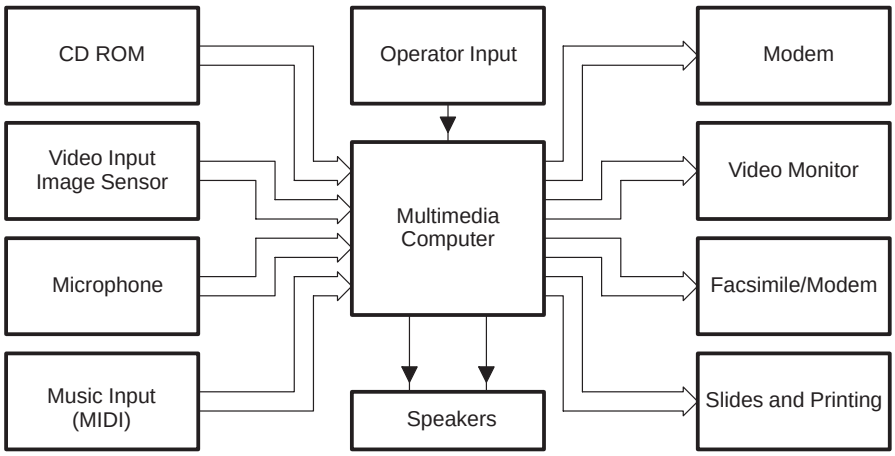
G.1	**Multimedia Applications**	**G-2**
G.2	**Telecommunications Applications**	**G-5**
G.3	**Dedicated Speech Synthesis Applications**	**G-10**
G.4	**Servo Control/Disk Drive Applications**	**G-12**
G.5	**Modem Analog Front-End Applications**	**G-15**
G.6	**Advanced Digital Electronics Applications for Consumers**	**G-18**

G.1 Multimedia Applications

Multimedia integrates different media through a centralized computer. These media can be visual or audio and can be input to or output from the central computer via a number of technologies. The technologies can be digital based or analog based (such as audio or video tape recorders). The integration and interaction of media enhances the transfer of information and can accommodate both analysis of problems and synthesis of solutions.

Figure G–1 shows both the central role of the multimedia computer and the multimedia system's ability to integrate the various media to optimize information flow and processing.

Figure G–1. System Block Diagram



G.1.1 System Design Considerations

Multimedia systems can include various grades of audio and video quality. The most popular video standard currently used (VGA) covers 640 $\times$ 480 pixels with 1, 2, 4, and 8-bit memory-mapped color. Also, 24-bit true color is supported, and 1024 $\times$ 768 (beyond VGA) resolution has emerged. There are two grades of audio. The lower grade accommodates 11.25-kHz sampling for 8-bit monaural systems, while the higher grade accommodates 44.1-kHz sampling for 16-bit stereo.

Audio specifications include a musical instrument digital interface (MIDI) with compression capability, which is based on keystroke encoding, and an input/output port with a 3-disc voice synthesizer. In the media control area, video disc, CD audio, and CD ROM player interfaces are included. Figure G–2 shows a multimedia subsystem.

The TLC32047 wide-band analog interface circuit (AIC) is well suited for multimedia applications because it features wide-band audio and up to 25-kHz sampling rates. The TLC32047 is a complete analog-to-digital and digital-to-analog interface system for the TMS320 DSPs. The nominal bandwidths of the filters accommodate 11.4 kHz, and this bandwidth is programmable. The application circuit shown in Figure G–2 handles both speech encoding and modem communication functions, which are associated with multimedia applications.

Figure G–2. Multimedia Speech Encoding and Modem Communication

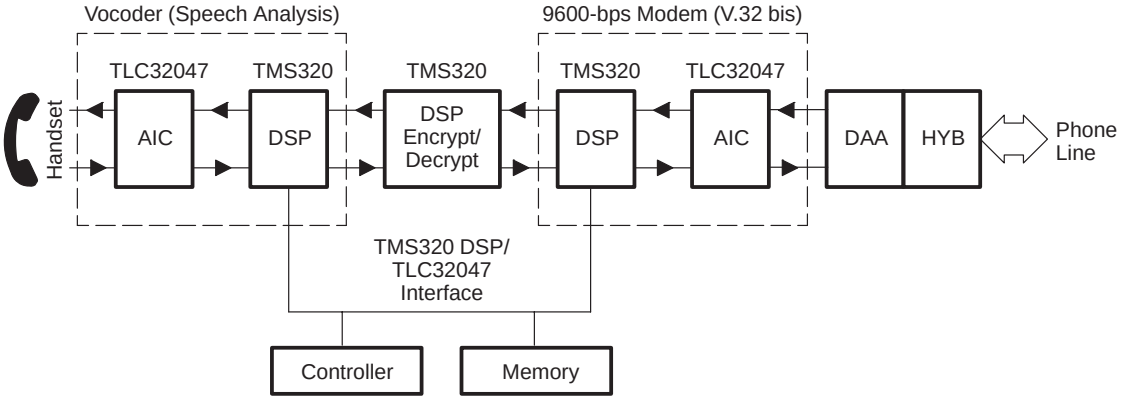
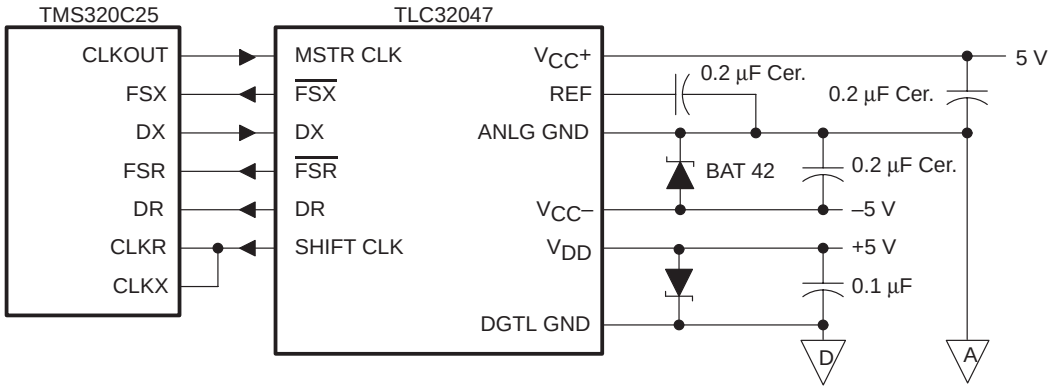


Figure G–3 shows the interfacing of the TMS320C25 DSP to the TLC32047 AIC that constitutes the building blocks of the 9600-bps V.32 bis modem shown in Figure G–2.

Figure G–3. TMS320C25 to TLC32047 Interface



G.1.2 Multimedia-Related Devices

As shown in Table H–1, TI provides a complete array of analog and graphics interface devices. These devices support the TMS320 DSPs for complete multimedia solutions.

Table H–1. Data Converter ICs

Device	Description	I/O	Resolution (Bits)	Conversion CLK Rate	Application
TLC320AC01	Analog interface (5 V only)	Serial	14	43.2 kHz	Portable modem and speech, multimedia
TLC32047	Analog interface (11.4 kHz BW) (AIC)	Serial	14	25 kHz	Speech, modem, and multimedia
TLC32046	Analog interface (AIC)	Serial	14	25 kHz	Speech and modems
TLC32044	Analog interface (AIC)	Serial	14	19.2 kHz	Speech and modems
TLC32040	Analog interface (AIC)	Serial	14	19.2 kHz	Speech and modems
TLC34075/6	Video palette	Parallel	Triple 8	135 MHz	Graphics
TLC34058	Video palette	Parallel	Triple 8	135 MHz	Graphics
TLC5502/3	Flash ADC	Parallel	8	20 MHz	Video
TLC5602	Video DAC	Parallel	8	20 MHz	Video
TLC5501	Flash ADC	Parallel	6	20 MHz	Video
TLC5601	Video DAC	Parallel	6	20 MHz	Video
TLC1550/1	ADC	Parallel	10	150 kHz	Servo ctrl / speech
TLC32071	Analog interface (AIC)	Parallel	8	1 MHz	Servo ctrl / disk drive
TMS57013/4	Dual audio DAC+ digital filter	Serial	16/18	32, 37.8, 44.1, 48 kHz	Digital audio

Table H–2. Switched-Capacitor Filter ICs

Device	Function	Order	Roll-Off	Power Out	Power Down
TLC2470	Differential audio filter amplifier	4	5 kHz	500 mW	Yes
TLC2471	Differential audio filter amplifier	4	3.5 kHz	500 mW	Yes
TLC10/20	General-purpose dual filter	2	CLK ÷ 50 CLK ÷ 100	N/A	No
TLC04/14	Low pass, Butterworth filter	4	CLK ÷ 50 CLK ÷ 100	N/A	No

For application assistance or additional information, please call TI Linear Applications at (214) 997–3772.

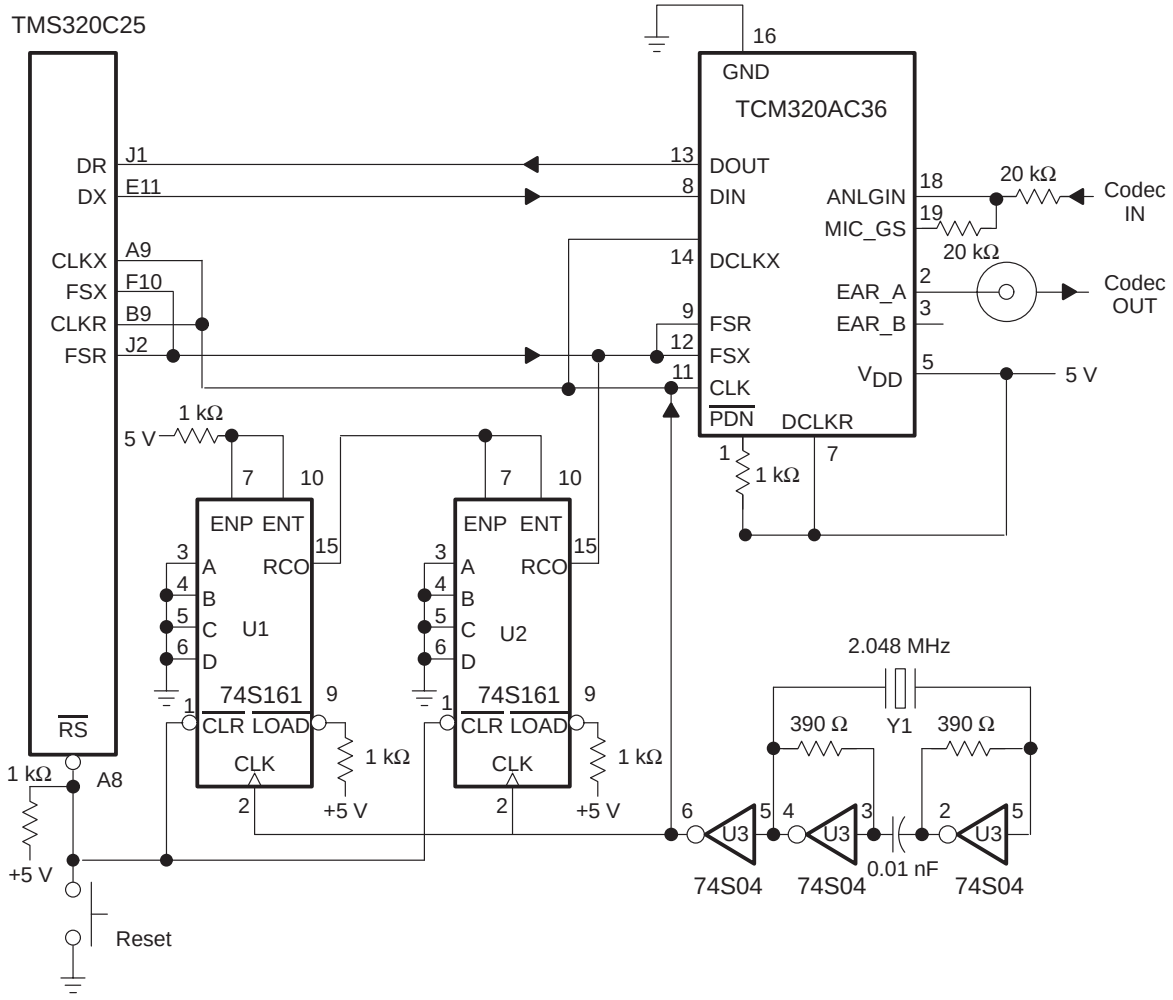
G.2 Telecommunications Applications

The TI linear product line focuses on three primary telecommunications application areas: subscriber instruments (telephones, modems, etc.), central office line card products, and personal communications. Subscriber instruments include the TCM508x DTMF tone encoder family, the TCM150x tone ringer family, the TCM1520 ring detector, and the TCM3105 FSK modem. Central office line card products include the TCM29Cxx combo (combined PCM filter plus codec) family, the TCM420x subscriber line control circuit family, and the TCM1030/60 line card transient protector. Personal communication (PCN) and cellular products include the TCM320AC3x family of 5-volt voice-band audio processors (VBAP).

TI continues to develop new telecom integrated circuits, such as a high-performance 3-volt combo family for personal communications applications, and an RF power amplifier family for hand-held and mobile cellular phones.

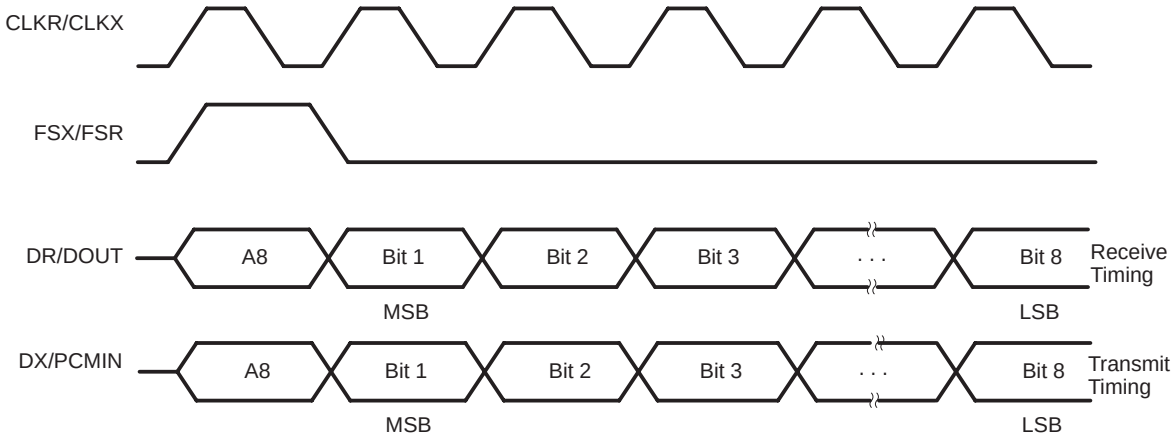
System Design Considerations. The size, network complexity, and compatibility requirements of telecommunications central office systems create demanding performance requirements. Combo voice-band filter performance is typically ± 0.15 dB in the passband. Idle channel noise must be on the order of 15 dBrnc0. Gain tracking (S/Q) and distortion must also meet stringent requirements. The key parameters for a SLIC device are gain, longitudinal balance, and return loss.

Figure G–4. Typical DSP/Combo Interface



The TCM320AC36 combo interfaces directly to the TMS320C25 serial port with a minimum of external components, as shown in Figure G–4. Half of hex inverter U3 and crystal Y1 form an oscillator that provides clock timing to the TCM320AC36. The synchronous 4-bit counters U1 and U2 generate an 8-kHz frame sync signal. DCLKR on the TCM320AC36 is connected to V_{DD}, placing the combo in fixed data-rate mode. Two 20-kΩ resistors connected to ANLGIN and MIC_GS set the gain of the analog input amplifier to 1. The timing is shown in Figure G–5.

Figure G–5. DSP/Combo Interface Timing



Telecommunications-Related Devices. Data sheets for the devices in Table H–3 are contained in the *1991 Telecommunications Circuits Databook* (literature number SCTD001B). To request your copy, contact your nearest Texas Instruments field sales office or call the Literature Response Center at (800) 477–8924.

For further information on these telecommunications products, please call TI Linear Applications at (214) 997–3772.

Table H–3. Telecom Devices

Device Number	Coding Law	Clock Rates MHz†	# of Bits	Comments
Codec/Filter				
TCM29C13	A and μ	1.544, 1.536, 2.048	8	C.O. and PBX line cards
TCM29C14	A and μ	1.544, 1.536, 2.048	8	Includes 8th-bit signal
TCM29C16	μ	2.048	8	16-pin package
TCM29C17	A	2.048	8	16-pin package
TCM29C18	μ	2.048	8	Low-cost DSP interface
TCM29C19	μ	1.536	8	Low-cost DSP interface
TCM29C23	A and μ	Up to 4.096	8	Extended frequency range
TCM29C26	A and μ	Up to 4.096	8	Low-power TCM29C23
TCM320AC36	μ and Linear	Up to 4.096	8 and 13	Single voltage (+5) VBAP
TCM320AC37	A and Linear	Up to 4.096	8 and 13	Single voltage (+5) VBAP
TCM320AC38	μ and Linear	Up to 4.096	8 and 13	Single voltage (+5) GSM
TCM320AC39	A and Linear	Up to 4.096	8 and 13	Single voltage (+5) GSM
TP3054/64	μ	1.544, 1.536, 2.048	8	National Semiconductor second source
TP3054/67	A	1.544, 1.536, 2.048	8	National Semiconductor second source
TLC320AC01	Linear	43.2 kHz	14	5-volt-only analog interface
TLC32040/1	Linear	Up to 19.2-kHz sampling	14	For high-dynamic linearity
TLC32044/5	Linear	Up to 19.2-kHz sampling	14	For high-dynamic linearity
TLC32046	Linear	Up to 25-kHz sampling	14	For high-dynamic linearity
TLC32047	Linear	Up to 25-kHz sampling	14	For high-dynamic linearity
Transient Suppressor				
TCM1030	Transient suppressor for SLIC-based line card			(30 A max)
TCM1060	Transient suppressor for SLIC-based line card			(60 A max)

† Unless otherwise noted

Table H–4. Switched-Capacitor Filter ICs

Device	Function	Order	Roll-Off	Power Out	Power Down
TLC2470	Differential audio filter amplifier	4	5 kHz	500 mW	Yes
TLC2471	Differential audio filter amplifier	4	3.5 kHz	500 mW	Yes
TLC10/20	General-purpose dual filter	2	CLK ÷ 50 CLK ÷ 100	N/A	No
TLC04/14	Low pass, Butterworth filter	4	CLK ÷ 50 CLK ÷ 100	N/A	No

Figure G–6. General Telecom Applications

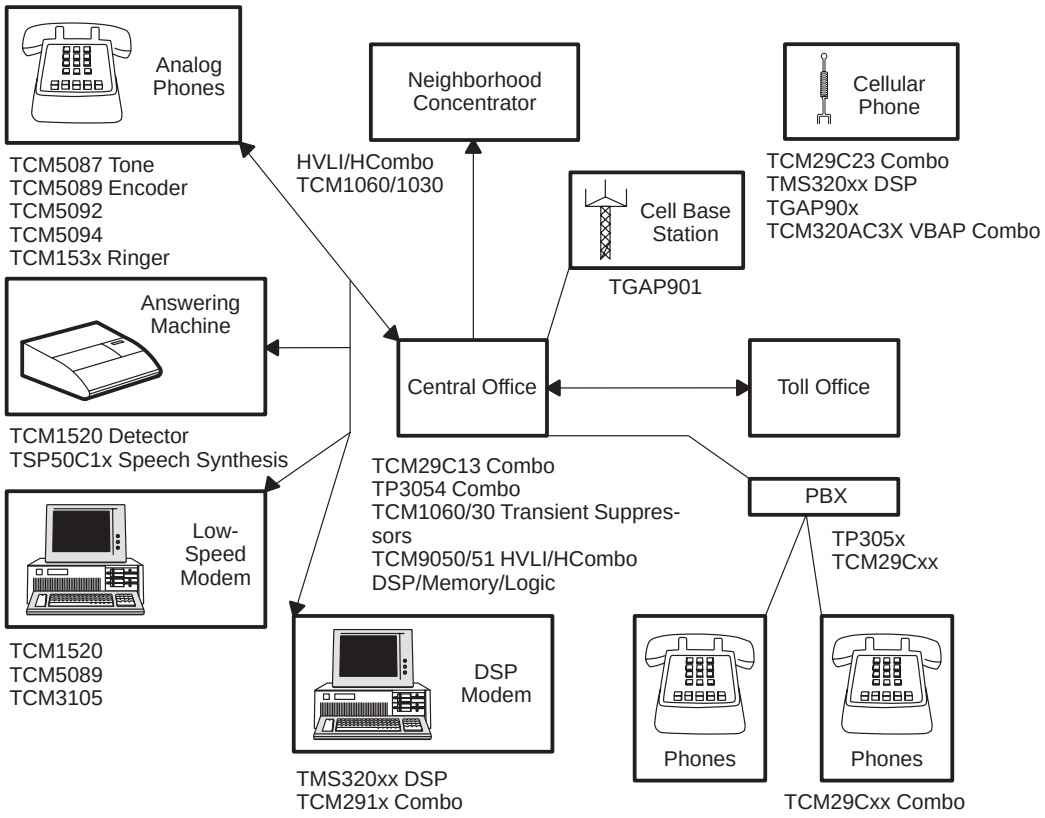
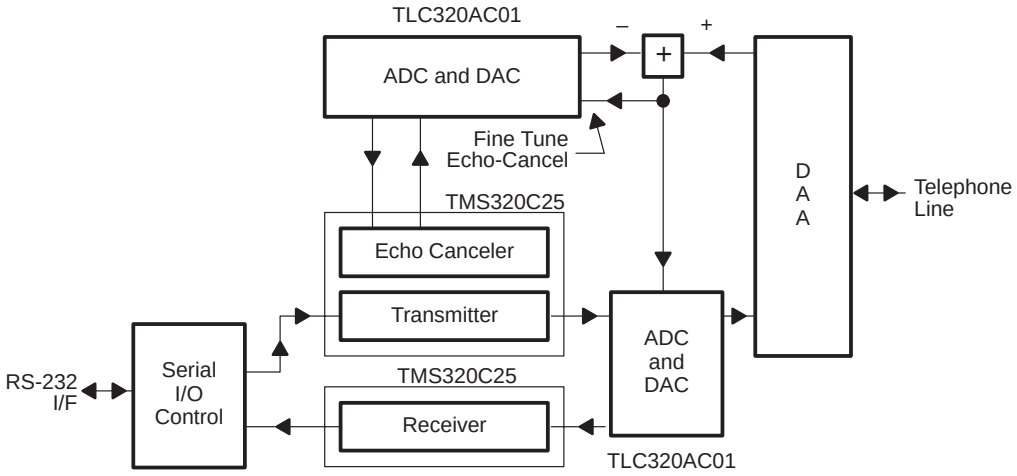


Figure G–7. Generic Telecom Application



G.3 Dedicated Speech Synthesis Applications

For dedicated speech synthesis applications, Texas Instruments offers a family of dedicated speech synthesizer chips. This speech technology has been used in a wide range of products including games, toys, burglar alarms, fire alarms, automobiles, airplanes, answering machines, voice mail, industrial control machines, office machines, advertisements, novelty items, exercise machines, and learning aids.

Dedicated speech synthesis chips are effective in low-cost applications. The speech synthesis technology provided by the dedicated chips is either LPC (linear-predictive coding) or CVSD (continuously variable slope delta modulation). Table H–5 shows the characteristics of the TI voice synthesizers.

Table H–5. Voice Synthesizers

TI Voice Synthesizers:						
Device	**Microprocessor**	**Synthesis Method**	**I/O Pins**	**On-Chip Memory (Bits)**	**External Memory**	**Data Rate (Bits/Sec)**
TSP50C4x	8-bit	LPC–10	20/32	64K/128K	VROM	1200–2400
TSP50C1x	8-bit	LPC–12	10	64K/128K	VROM	1200–2400
TSP53C30	8-bit	LPC–10	20	N/A	From host µP	1200–2400
TSP50C20	8-bit	LPC–10	32	N/A	EPROM	1200–2400
TMS3477	N/A	CVSD	2	None	DRAM	16K–32K

TI has low-cost memories that are ideal to use with speech synthesis chips. Texas Instruments can also be of assistance in developing and processing the speech data that is used in these speech synthesis systems. Table H–6 shows speech memory devices of different capabilities. Additionally, audio filters are outlined in Table H–7.

Table H–6. Speech Memories

TSP60Cxx Family of Speech ROMs					
	TSP60C18	TSP60C19	TSP60C20	TSP60C80	TSP60C81
Size	256K	256K	256K	1M	1M
No. of Pins	16	16	28	28	28
Interface	Parallel 4-bit	Serial	Parallel/serial 8-bit	Serial	Parallel 4-bit
For use with:	TSP50C1x	TSP50C4x	TSP50C4x	TSP50C4x	TSP50C1x

Table H–7. Switched-Capacitor Filter ICs

Device	Function	Order	Roll-Off	Power Out	Power Down
TLC2470	Differential audio filter amplifier	4	5 kHz	500 mW	Yes
TLC2471	Differential audio filter amplifier	4	3.5 kHz	500 mW	Yes
TLC10/20	General-purpose dual filter	2	CLK ÷ 50 CLK ÷ 100	N/A	No
TLC04/14	Low pass, Butterworth filter	4	CLK ÷ 50 CLK ÷ 100	N/A	No

Speech Synthesis Development Tools

Software:

EVM	Code development tool

Speech:

SAB	Speech audition board
SD85000	PC-based speech analysis system

System:

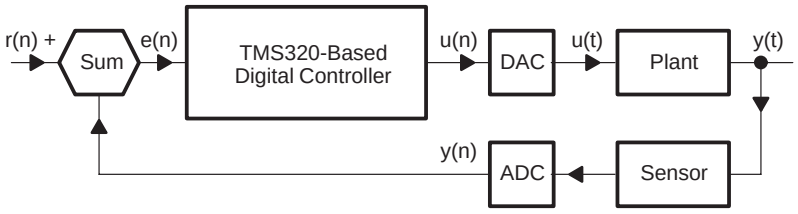
SEB	System emulator board
SEB60Cxx	System emulator boards for speech memories

For further information on these speech synthesis products, please call TI Linear Applications at (214) 997–3772.

G.4 Servo Control/Disk Drive Applications

Several years ago, most servo control systems used only analog circuitry. However, the growth of digital signal processing has made digital control theory a reality. Figure G–8 shows a block diagram of a generic digital control system using a DSP, along with an ADC and DAC.

Figure G–8. Generic Servo Control Loop



In a DSP-based control system, the control algorithm is implemented via software. No component aging or temperature drift is associated with digital control systems. Additionally, sophisticated algorithms can be implemented and easily modified to upgrade system performance.

System Design Considerations. TMS320 DSPs have facilitated the development of high-speed digital servo control for disk drive and industrial control applications. Disk drives have increased storage capacity from 5 megabytes to over 1 gigabyte in the past decade, which equates to a 23,900 percent growth in capacity. To accommodate these increasingly higher densities, the data on the servo platters, whether servo-positioning or actual storage information, must be converted to digital electronic signals at increasingly closer points in relation to the platter “pick-off” point. The ADC must have increasingly higher conversion rates and greater resolution to accommodate the increasing bandwidth requirements of higher storage densities. In addition, the ADC conversion rates must increase to accommodate the shorter data retrieval access time.

Figure G–9 shows a block diagram of a disk drive control system.

Figure G–9. Disk Drive Control System Block Diagram

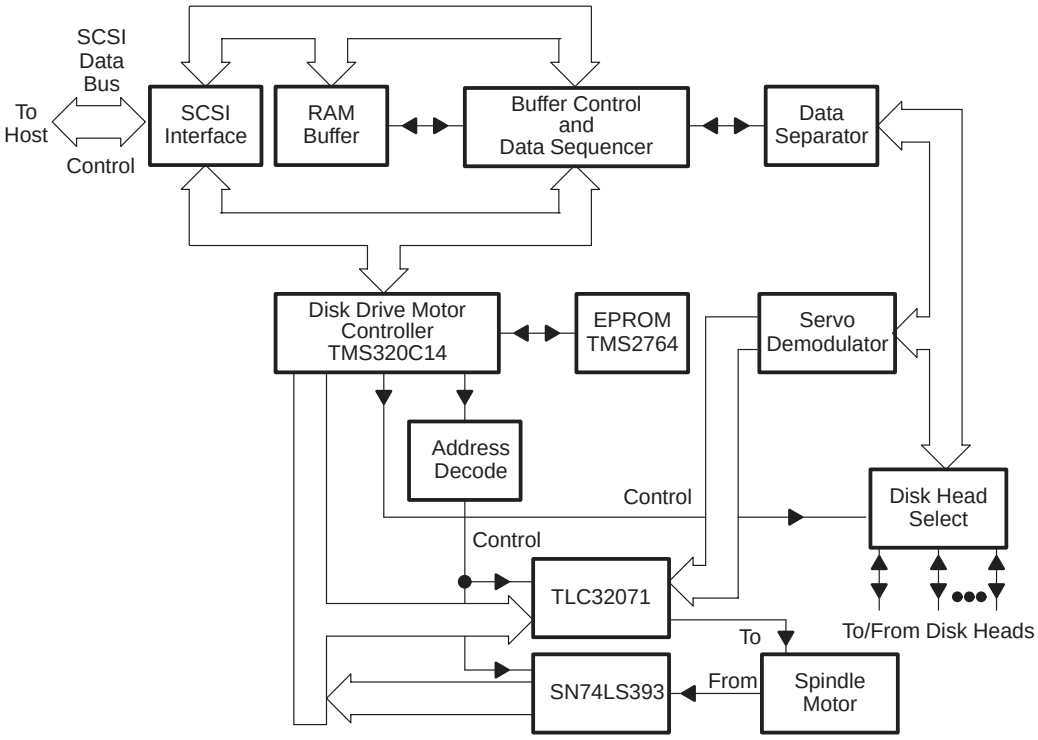


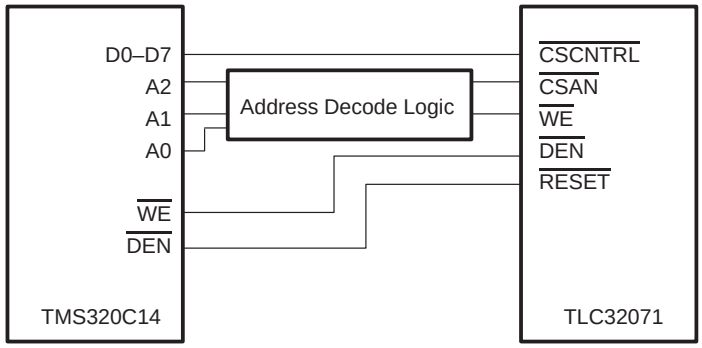
Table H–8 lists analog/digital interface devices used for servo control.

Table H–8. Control-Related Devices

Function	Device	Bits	Speed	Channels	Interface
ADC	TLC1550	10	3–5 µs	1	Parallel
	TLC1551	10	3–5 µs	1	Parallel
	TLC5502/3	8	50 ns (flash)	1	Parallel
	TLC0820	8	1.5 µs	1	Parallel
	TLC1225	13	12 µs	1 (Diff.)	Parallel
	TLC1558	10	3–5 µs	8	Parallel
	TLC1543	10	21 µs	11	Serial
	TLC1549	10	21 µs	1	Serial
DAC	TLC7524	8	9 MHz	1	Parallel
	TLC7628	8	9 MHz	(Dual)	Parallel
	TLC5602	8	30 MHz	1	Parallel
AIC	TLC32071	8 (ADC)	1 µs 9 MHz	8 1	Parallel

Figure G–10 shows the interfacing of the TMS320C14 and the TLC32071.

Figure G–10. TMS320C14 – TLC32071 Interface



For further information on these servo control products, please call TI Linear Applications at (214) 997–3772.

G.5 Modem Applications

High-speed modems (9,600 bps and above) require a great deal of analog signal processing in addition to digital signal processing. Designing both high-speed capabilities and slower fall-back modes poses significant engineering challenges. TI offers a number of analog front-end (AFE) circuits to support various high-speed modem standards.

The TLC32040, TLC32044, TLC32046, TLC32047, and TLC320AC01 analog interface circuits (AIC) are especially suited for modem applications by the integration of an input multiplexer, switched capacitor filters, high resolution 14-bit ADC and DAC, a four-mode serial port, and control and timing logic. These converters feature adjustable parameters, such as filtering characteristics, sampling rates, gain selection, (sin x)/x correction (TLC32044, TLC32046, and TLC32047 only), and phase adjustment. All these parameters are software programmable, making the AIC suitable for a variety of applications. Table H–9 has the description and characteristics of these devices.

Table H–9. Modem AFE Data Converters

Device	Description	I/O	Resolution (Bits)	Conversion Rate
TLC32040	Analog interface chip (AIC)	Serial	14	19.2 kHz
TLC32041	AIC without on-board V_{REF}	Serial	14	19.2 kHz
TLC32044	Telephone speed/modem AIC	Serial	14	19.2 kHz
TLC32045	Low-cost version of the TLC32044	Serial	14	19.2 kHz
TLC32046	Wide-band AIC	Serial	14	25 kHz
TLC32047	AIC with 11.4-kHz BW	Serial	14	25 kHz
TLC320AC01	5-volt-only AIC	Serial	14	43.2 kHz
TCM29C18	Companding codec/filter	PCM	8	8 kHz
TCM29C23	Companding codec/filter	PCM	8	16 kHz
TCM29C26	Low-power codec/filter	PCM	8	16 kHz
TCM320AC36	Single-supply codec/filter	PCM and Linear	8	25 kHz

The AIC interfaces directly with serial-input TMS320 DSPs, which execute the modem's high-speed encoding and decoding algorithms. The TLC3204x family performs level-shifting, filtering, and A/D and D/A data conversion. The DSP's many software-programmable features provide the flexibility required for modem operations and make it possible to modify and upgrade systems easily. Under DSP control, the AIC's sampling rates permit designers to include fall-back modes without additional analog hardware in most cases. Phase adjustments can be made in real time so that the A/D and D/A conversions can be synchronized with the upcoming signal. In addition, the chip has a built-in loopback feature to support modem self-test requirements.

For further information or application assistance, please call TI Linear Applications at (214) 997–3772.

Figure G–11. High-Speed V.32 Bis and Multistandard Modem With the TLC320AC01 AIC

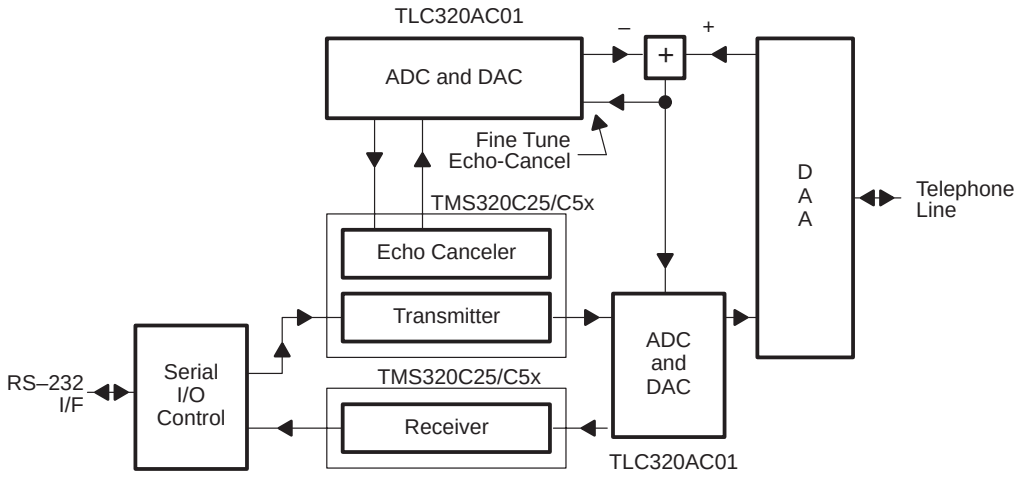


Figure G–11 shows a V.32 bis modem implementation using the TMS320C25 and a TLC320AC01. The upper TMS320C25 performs echo cancellation and transmit data functions, while the lower TMS320C25 performs receive data and timing recovery functions. The echo canceler simulates the telephone channel and generates an estimated echo of the transmit data signal. The TLC320AC01 performs the following functions:

Upper TLC320AC01 D/A Path: Converts the estimated echo, as computed by the upper TMS320C25, into an analog signal, which is subtracted from the receive signal.

Upper TLC320AC01 A/D Path: Converts the residual echo to a digital signal for purposes of monitoring the residual echo and continuously training the echo canceler for optimum performance. The converted signal is sent to the upper TMS320C25.

Lower TLC320AC01 D/A Path: Converts the upper TMS320C25 transmit output to an analog signal, performs a smoothing filter function, and drives the DAC.

Lower TLC320AC01 D/A Path: Converts the echo-free receive signal to a digital signal, which is sent to the lower TMS320C25 to be decoded.

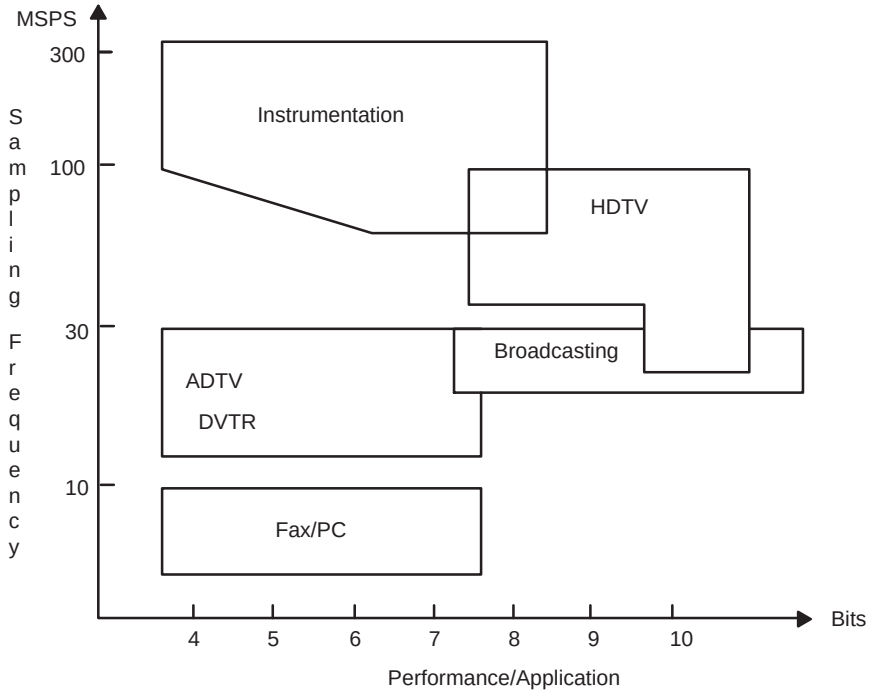
Note: Modem Implementation in Figure G–11

The example in Figure G–11 is for illustration only. In reality, one single TMS320C5x DSP can implement high-speed modem functions.

G.6 Advanced Digital Electronics Applications for Consumers

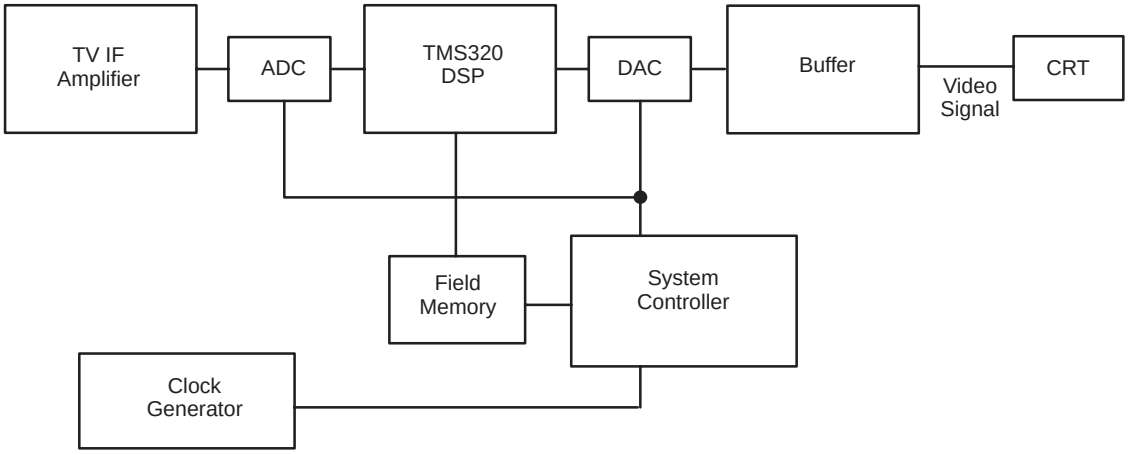
With the extensive use of the TMS320 DSPs in consumer electronics, much electromechanical control and signal processing can be done in the digital domain. Digital systems generally require some form of analog interface, usually in the form of high-performance ADCs and DACs. Figure G–12 shows the general performance requirements for a variety of applications.

Figure G–12. Applications Performance Requirements



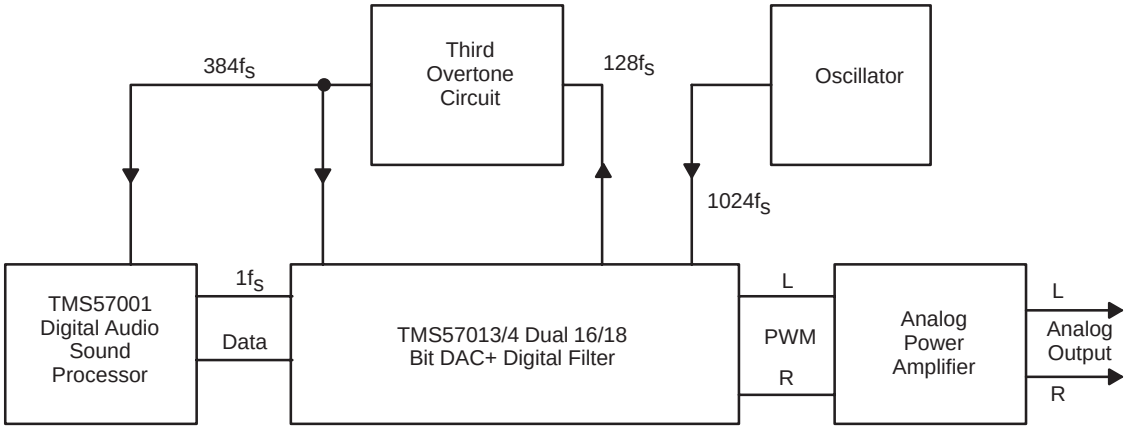
Advanced Television System Design Considerations. Advanced Digital Television (ADTV) is a technology that uses digital signal processing to enhance video and audio presentations and to reduce noise and ghosting. Because of these DSP techniques, a variety of features can be implemented, including frame store, picture-in-picture, improved sound quality, and zoom. The bandwidth requirements remain at the existing 6-MHz television allocation. From the IF(intermediate frequency) output, the video signal is converted by an 8-bit video ADC. The digital output can be processed in the digital domain to provide noise reduction, interpolation or averaging for digitally increased sharpness, and higher quality audio. The DSP digital output is converted back to analog by a video DAC, as shown in Figure G–13.

Figure G–13. Video Signal Processing Basic System



VCRs, compact disc and DAT players, and PCs are a few of the products that have taken a major position in the marketplace in the last ten years. The audio channels for compact disc and DAT require 16-bit A/D resolution to meet the distortion and noise standards. See Figure G–14 for a block diagram of a typical digital audio system.

Figure G–14. Typical Digital Audio Implementation



The motion and motor control systems usually use 8- to 10-bit ADCs for the lower frequency servo loop. Tape or disc systems use motor or motion control for proper positioning of the record or playback heads. With the storage medium compressing data into an increasingly smaller physical size, the positioning systems require more precision.

The audio processing becomes more demanding as higher fidelity is required. Better fidelity translates into lower noise and distortion in the output signal.

The TMS57013DW/57014DW 1-bit digital-to-analog converters (DAC) include an 8 times over sampling digital filter designed for digital audio systems, such as CDPs, DATs, CDIs, LDPs, digital amplifiers, car stereos, and BS tuners. They are also suitable for all systems that include digital sound processing like TVs, VCRs, musical instruments, NICAM systems, multimedia, etc.

The converters have dual channels so that the right and left stereo signals can be transformed into analog signals with only one chip. There are some functions that allow the customers to select the conditions according to their applications, such as muting, attenuation, de-emphasis, and zero data detection. These functions are controlled by external 16-bit serial data from a controller like a microcomputer.

The TMS5703DW/57014DW adopt 129-tap FIR filter and third-order $\Delta\Sigma$ modulation to get –75-dB stop band attenuation and 96-dB SNR. The output is PWM wave, which facilitates analog signal through a low-pass filter.

Table H–10 lists TI products for analog interfacing to digital systems.

Table H–10. Audio/Video Analog/Digital Interface Devices

Function	Device	Bits	Speed	Channels	Interface
Dual audio DAC+ digital filter	TMS57013/4	16/18	32, 37.8, 44.1, 48 kHz	2	Serial
Analog interface A/D D/A	TLC32071	 8 8	 2 μs 15 μs	 8 1	 Parallel Parallel
A/D	TLC1225	12	12 μs	1	Parallel
A/D	TLC1550	10	6 μs	1	Parallel
Video D/A	TLC5602	8	50 ns	1	Parallel
Video D/A	TL5602	8	50 ns	1	Parallel
Triple video D/A	TL5632	8	16 ns	3	Parallel
Triple flash A/D	TLC5703	8	70 ns	3	Parallel
Flash A/D	TLC5503	8	100 ns	1	Parallel
Flash A/D	TLC5502	8	50 ns	1	Parallel

For further information or application assistance, please call TI Linear Applications at (214) 997–3772.

Appendix H

Memories, Analog Converters, Sockets, and Crystals

This appendix provides product information regarding memories, analog converters, and sockets, which are manufactured by Texas Instruments and are compatible with the TMS320C2x. Information is also given regarding crystal frequencies, specifications, and vendors.

The contents of the major areas in this appendix are listed below.

Topic **Page**

H.1 Memories and Analog Converters H-2

H.2 Sockets H-3

H.3 Crystals H-4

H.1 Memories and Analog Converters

This section provides product information for EPROM memories, codecs, analog interface circuits, and A/D and D/A converters.

All of these devices can be interfaced with TMS320C2x processors (see Chapter 6 for hardware interface designs). Refer to *Digital Signal Processing Applications with the TMS320* Family for additional information on interfaces using memories and analog conversion devices.

The following paragraphs give the name of each device and where the data sheet for that device is located in order to obtain further specification information if desired.

Data sheets for EPROM memories are located in the *MOS Memory Data Book* (literature number SMYD008).

TMS27C64
TMS27C128
TMS27C256
TMS27C512

Another EPROM memory, TMS27C291/292, is described in a data sheet ((literature number SMLS291A).

The TCM29C13/14/16/17 codecs and filters are described in the data sheet beginning on page 2–111 of the *Telecommunications Circuits Data Book* (literature number SCT001). An analog interface for the DSP using a codec and filter is provided by the TCM29C18/19 data sheet (literature number SCT021).

The data sheet for the TLC32040 analog interface circuit is provided in the *Interface Circuits Data Book* (literature number SLYD002).

In the same book are data sheets for A/D and D/A converters. The names of the devices are as follows:

TLC0820
TLC1205/1225
TLC7524

H.2 Sockets

The sockets produced by Texas Instruments are designed for high-density packaging needs. The production sockets and burn-in/test sockets for PGA, PLCC, and CER-QUAD packages are compatible with the TMS320C2x devices.

For additional information about TI sockets, contact the nearest TI sales office or:

Texas Instruments Incorporated
Connector Systems Dept, M/S 14–3
Attleboro, MA 02703
(617) 699–5242/5269
Telex: 92–7708

H.3 Crystals

This section lists the commonly used crystal frequencies, crystal specification requirements, and the names of suitable vendors.

Table I–1 lists the commonly used crystal frequencies and the devices with which they can be used.

Table I–1. Commonly Used Crystal Frequencies

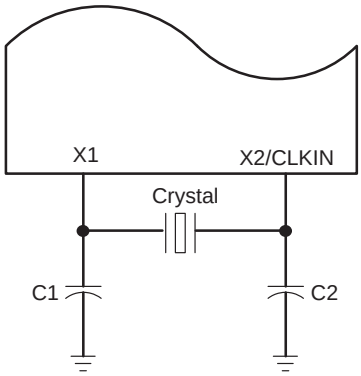
Device	Frequency
TMS320C25	40.96 MHz

When connected across X1 and X2/CLKIN of the TMS320 processor, a crystal enables the internal oscillator; see Figure F–1. The frequency of CLKOUT is one-fourth the crystal fundamental frequency. Crystal specification requirements are listed below.

Load capacitance = 20 pF
Series resistance = 30 ohm
Power dissipation = 1 mW

Parallel resonant crystals of 20 MHz and below use fundamental mode.
25-MHz operation may require a third-overtone crystal.
40-MHz operation requires a third-overtone crystal.

Figure H–1.Crystal Connection



The TMS320C25 operating at 40.96 MHz requires a parallel-resonant third-overtone oscillator (see subsection 6.1.2 for a detailed description of this oscillator design). If a packed clock oscillator is used, oscillator design is of no concern.

Vendors of crystals suitable for use with TMS320 devices are listed below.

RXD, Inc.
Norfolk, NB
(800) 228–8108

N.E.L. Frequency Controls, Inc.
Burlington, WI
(414) 763–3591

CTS Knight, Inc.
Contact the local distributor.

Appendix I

ROM Codes

The size of a printed circuit board must be considered in many DSP applications. To fully utilize the board space, Texas Instruments offers two options that reduce the chip count and provide a single-chip solution to its customers. These options incorporate 4K words of on-chip program from either a mask programmable ROM or an EPROM. This allows the customer to use a code-customized processor for a specific application while taking advantage of the following:

- Greater memory expansion
- Lower system cost
- Less hardware and wiring
- Smaller PCB

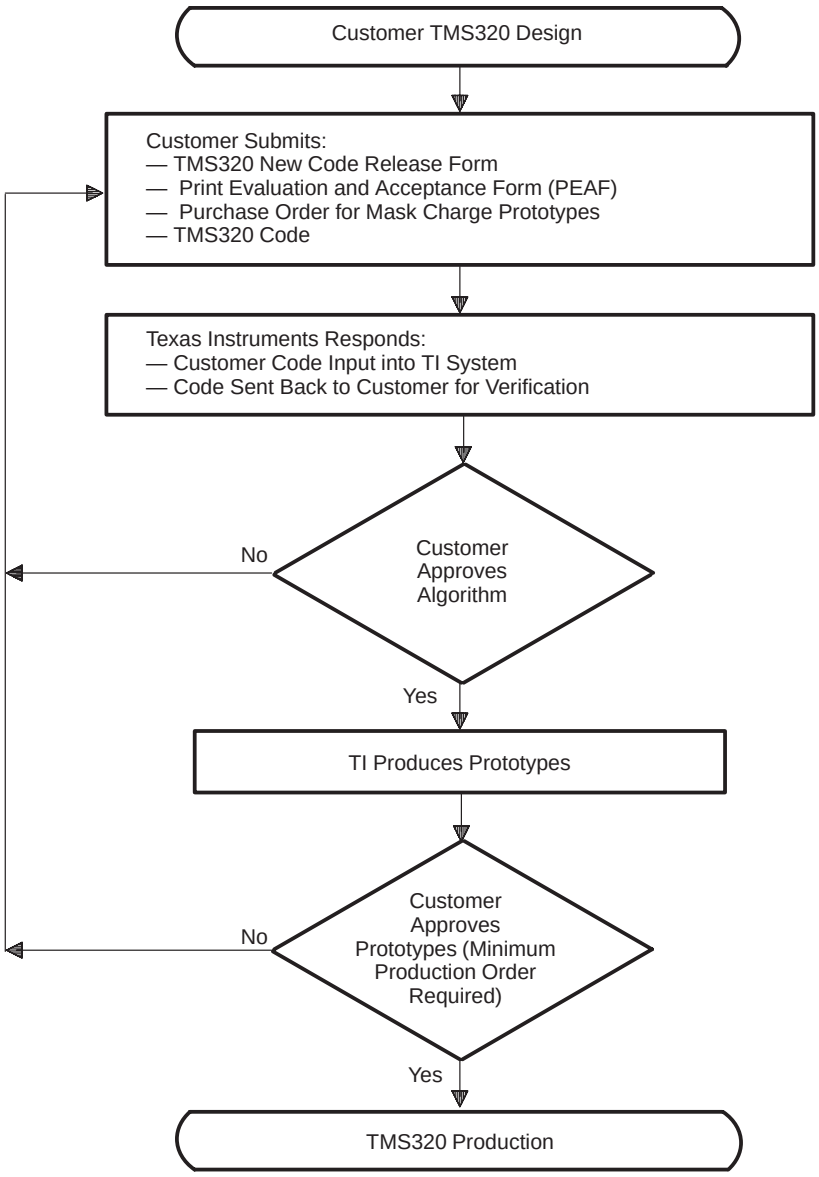
If used often, the routine or entire algorithm can be programmed into the on-chip ROM of a TMS320 DSP. TMS320 programs can also be expanded by using external memory; this reduces chip count and allows for a more flexible program memory. Multiple functions are easily implemented by a single device, thus enhancing system capabilities.

TMS320 Development Tools are used to develop, test, refine, and finalize the algorithms. The microprocessor/microcomputer (MP/$\overline{\text{MC}}$) mode is available on all ROM-coded TMS320 DSP devices when accessing either on-chip or off-chip memory is required. The microprocessor mode is used to develop, test, and refine a system application. In this mode of operation, the TMS320 acts as a standard microprocessor by using external program memory. When the algorithm has been finalized, the designer may submit the code to Texas Instruments for masking into the on-chip program ROM. At that time, the TMS320 becomes a microcomputer that executes customized programs out of the on-chip ROM. Should the code need changing or upgrading, the TMS320 may once again be used in the microprocessor mode. This shortens the field upgrade time and avoids the possibility of inventory obsolescence.

Figure I–1 illustrates the procedural flow for TMS320 masked parts. When ordering, there is a one-time/nonrefundable charge for mask-tooling. A minimum production order per year is required for any masked-ROM device. ROM codes will be deleted from the TI system one year after the last delivery.

A digital signal processor with the EPROM option is the solution for low-volume production orders. The EPROM option allows for form-factor emulation. Field upgrades and changes are possible with the EPROM option.

Figure I–1. TMS320 ROM Code Flowchart



A TMS320 ROM code may be submitted in one of the following formats (the preferred media is 5 1/4-in floppies):

5 1/4-in Floppy:	TI-tagged or COFF format from cross-assembler
EPROM (TMS320):	TMS320E14, TMS320E15, TMS320E17, TMS320E25
EPROM (others):	TMS27C64
PROM:	TBP28S166, TBP28S86
Modem (BBS):	TI-tagged or COFF format from cross-assembler

When a code is submitted to Texas Instruments for masking, the code is reformatted to accommodate the TI mask generation system. System-level verification by the customer is therefore necessary. Although the code has been reformatted, it is important that the changes remain transparent to the user and do not affect the execution of the algorithm. The formatting changes involve the removal of address relocation information (the code address begins at the base address of the ROM in the TMS320 device and progresses without gaps to the last address of the ROM on the TMS320 device) and the addition of data in the reserved locations of the ROM for device ROM test. Note that because these changes have been made, a checksum comparison is not a valid means of verification.

With each masked device order, the customer must sign a disclaimer stating:

”The units to be shipped against this order were assembled, for expediency purposes, on a prototype (that is, non-production qualified) manufacturing line, the reliability of which is not fully characterized. Therefore, the anticipated inherent reliability of these prototype units cannot be expressly defined.”

and a release stating:

”Any masked ROM device may be resymbolized as TI standard product and resold as though it were an unprogrammed version of the device at the convenience of Texas Instruments.”

Contact the nearest TI Field Sales Office for more information on procedures, leadtimes, and cost.

Appendix J

Quality and Reliability

The quality and reliability performance of Texas Instruments Microprocessor and Microcontroller Products, which include the five generations of TMS320 digital signal processors, relies on feedback from:

- Our customers
- Our total manufacturing operation from front-end wafer fabrication to final shipping inspection
- Product quality and reliability monitoring.

Our customer's perception of quality must be the governing criterion for judging performance. This concept is the basis for Texas Instruments Corporate Quality Policy, which is as follows:

"For every product or service we offer, we shall define the requirements that solve the customer's problems, and we shall conform to those requirements without exception."

Texas Instruments offers a leadership reliability qualification system, based on years of experience with leading-edge memory technology as well as years of research in customer requirements. Quality and reliability programs at TI are therefore based on customer input and internal information to achieve constant improvement in quality and reliability.

Note:

Texas Instruments reserves the right to make changes in MOS semiconductor test limits, procedures, or processing without notice. Unless prior arrangements for notification have been made, TI advises all customers to reverify current test and manufacturing conditions prior to relying on published data.

J.1 Reliability Stress Tests

Accelerated stress tests are performed on new semiconductor products and process changes to ensure product reliability excellence. The typical test environments used to qualify new products or major changes in processing are:

- ❑ High-temperature operating life
- ❑ Storage life
- ❑ Temperature cycling
- ❑ Biased humidity
- ❑ Autoclave
- ❑ Electrostatic discharge
- ❑ Package integrity
- ❑ Electromigration
- ❑ Channel-hot electrons (performed on geometries less than 2.0μm).

Typical events or changes that require internal requalification of product include:

- ❑ New die design, shrink, or layout
- ❑ Wafer process (baseline/control systems, flow, mask, chemicals, gases, dopants, passivation, or metal systems)
- ❑ Packaging assembly (baseline control systems or critical assembly equipment)
- ❑ Piece parts (such as lead frame, mold compound, mount material, bond wire, or lead finish)
- ❑ Manufacturing site.

TI reliability control systems extend beyond qualification. Total reliability controls and management include a product reliability monitor and final product release controls. MOS memories, utilizing high-density active elements, serve as leading indicators in wafer-process integrity at TI MOS fabrication sites, enhancing all MOS logic device yields and reliability. Thousands of logic devices per month are randomly tested to ensure product reliability and excellence.

Table K–1 lists the microprocessor and microcontroller reliability tests, the duration of the test, and sample size. The following terms define or describe these tests:

AOQ (Average Outgoing Quality)
Amount of defective product in a population, usually expressed in terms of parts per million (PPM).

FIT (Failure in Time) Estimated field failure rate in number of failures per billion power-on device hours; 1000 FIT = 0.1% failure per 1000 device hours.

Operating lifetest Device dynamically exercised at a high ambient temperature (usually 125°C) to simulate field usage that would expose the device to a much lower ambient temperature (such as 55°C). Using a derived high temperature, a 55° C ambient failure rate can be calculated.

High-temperature storage
Device exposed to 150°C unbiased condition. Bond integrity is stressed in this environment.

Biased humidity Moisture and bias used to accelerate corrosion-type failures in plastic packages. Conditions must include 85°C ambient temperature with an 85% relative humidity (RH). Typical bias voltage is +5V and ground on alternating pins.

Autoclave (pressure cooker)
Plastic-packaged devices exposed to moisture at 121° C using a pressure of one atmosphere above normal pressure. The pressure forces moisture permeation of the package and accelerates corrosion mechanisms (if present) on the device. External package contaminants can also be activated and caused to generate inter-pin current leakage paths.

Temperature cycle Device exposed to severe temperature extremes in an alternating fashion (–65°C for 15 minutes and 150°C for 15 minutes per cycle) for at least 1000 cycles. Package strength, bond quality, and consistency of assembly process are stressed in this environment.

Thermal shock Test similar to the temperature cycle test, but involving a liquid-to-liquid transfer, per MIL-STD-883C, Method 1011.

PIND Particle Impact Noise Detection test. A nondestructive test to detect loose particles inside a device cavity.

Mechanical Sequence:

Fine and gross leak	Per MIL-STD-883C, Method 1014.5
Mechanical shock	Per MIL-STD-883C, Method 2002.3, 1500g, 0.5 ms, Condition B
PIND (optional)	Per MIL-STD-883C, Method 2020.4
Vibration, variable frequency	Per MIL-STD-883C, Method 2007.1, 20g, Condition A
Constant acceleration	Per MIL-STD-883C, Method 2001.2, 20 kg, Condition D, Y1 Plane min
Fine and gross leak	Per MIL-STD-883C, Method 1014.5
Electrical test	To data sheet limits

Thermal Sequence:

Fine and gross leak	Per MIL-STD-883C, Method 1014.5
Solder heat (optional)	Per MIL-STD-750C, Method 1014.5
Temperature cycle (10 cycles minimum)	Per MIL-STD-883C, Method 1010.5, –65 to +150°C, Condition C
Thermal shock (10 cycles minimum)	Per MIL-STD-883C, Method 1011.4, –55 to +125°C, Condition B
Moisture resistance	Per MIL-STD-883C, Method 1004.4
Fine and gross leak	Per MIL-STD-883C, Method 1014.5
Electrical test	To data sheet limits

Thermal/Mechanical Sequence:

Fine and gross leak	Per MIL-STD-883C, Method 1014.5
Temperature cycle (10 cycles minimum)	Per MIL-STD-883C, Method 1010.5, -65 to +150°C, Condition C
Constant acceleration	Per MIL-STD-883C, Method 2001.2, 30 kg, Y1 Plane
Fine and gross leak	Per MIL-STD-883C, Method 1014.5
Electrical test	To data sheet limits
Electrostatic discharge	Per MIL-STD-883C, Method 3015
Solderability	Per MIL-STD-883C, Method 2003.3
Solder heat	Per MIL-STD-750C, Method 2031, 10 sec
Salt atmosphere	Per MIL-STD-883C, Method 1009.4, Condition A, 24 hrs min
Lead pull	Per MIL-STD-883C, Method 2004.4, Condition A
Lead integrity	Per MIL-STD-883C, Method 2004.4, Condition B1

Electromigration	Accelerated stress testing of conductor patterns to ensure acceptable lifetime of power-on operation
Resistance to solvents	Per MIL-STD-883C, Method 2015.4

Table K–1.Microprocessor and Microcontroller Tests

Test	Duration	Sample Size	
		Plastic	Ceramic
Operating life, 125°C, 5.0 V	1000 hrs	129	129
Operating life, 150°C, 5.0 V	1000 hrs	77†	77
Storage life, 150°C	1000 hrs	77	77
Biased 85°C/85 percent RH, 5.0 V	1000 hrs	129	–
Autoclave, 121°C, 1 ATM	240 hrs	77	–
Temperature cycle, -65 to 150°C	1000 cyc	129	129
Thermal shock, -65 to 150°C	500 cyc	77	77
Electrostatic discharge ± 2 kV		15	15
Latch-up (CMOS devices only)		5	5
Mechanical sequence		–	38
Thermal sequence		–	38
Thermal/mechanical sequence		–	38
PIND		–	45
Internal water vapor		–	3
Solderability		22	22
Solder heat		22	22
Resistance to solvents		15	15
Lead integrity		15	15
Lead pull		22	–
Lead finish adhesion		15	15
Salt atmosphere		15	15
Flammability (UL94-V0)		3	–
Thermal impedance		5	5

† If junction temperature does not exceed plasticity of package.

Table K–2 provides a list of the TMS320C2x devices, the approximate number of transistors, and the equivalent gates. The numbers have been determined from design verification runs.

Table K–2.TMS320C2x Transistors

Device		# Transistors	# Gates
CMOS:	TMS320C25	160K	40K
	TMS320E25	160K	40K
	TMS320C26	160K	40K

TI qualification test updates are available upon request at no charge. TI will consider performing any additional reliability test(s), if requested. For more information on TI quality and reliability, programs, contact the nearest TI Field Sales Office.

Appendix K

Development Support

Texas Instruments offers an extensive line of development tools for the TMS320C2x generation of DSPs, including tools to evaluate the performance of the processors, generate code, develop algorithm implementations, and fully integrate and debug software and hardware modules.

The following products support development of TMS320C2x-based applications:

Code Generation Tools:

- Optimizing ANSI C compiler (TMS320C25 only)
- Macro assembler/linker
- Digital filter design package

System Integration and Debug Tools:

- Simulator
- Evaluation module (EVM)
- In-circuit emulator (XDS/22)
- Analog interface board (AIB2)

Each TMS320C2x support product is described in the *TMS320 Family Development Support Reference Guide* (literature number SPRU011C). In addition, more than 100 TMS320 third-party developers provide support products to complement TI's offering. For more information on third-party support refer to the *TMS320 Third Party Reference Guide* (literature number SPRU052A). To request a copy of either document, contact the TI Literature Response Center at (800) 477–8924.

For information on pricing and availability, contact the nearest TI Field Sales Office or authorized distributor.

K.1 Device and Development Support Tool Nomenclature

To designate the stages in the product development cycle, Texas Instruments assigns prefixes to the part numbers of all TMS320 devices and support tools. Each TMS320 member has one of three prefixes: TMX, TMP, and TMS. Texas Instruments recommends two of three possible prefix designators for its support tools: TMDX and TMDS. These prefixes represent evolutionary stages of product development from engineering prototypes (TMX/TMDX) through fully qualified production devices/tools (TMS/TMDS). This development flow is defined below.

Device Development Evolutionary Flow:

TMX Experimental device that is not necessarily representative of the final device's electrical specifications.

TMP Final silicon die that conforms to the device's electrical specifications but has not completed quality and reliability verification.

TMS Fully qualified production device.

Support Tool Development Evolutionary Flow:

TMDX Development support product that has not yet completed Texas Instruments internal qualification testing.

TMDS Fully qualified development support product.

TMX and TMP devices and TMDX development support tools are shipped against the following disclaimer:

"Developmental product is intended for internal evaluation purposes."

TMS devices and TMDS development support tools have been fully characterized, and the quality and reliability of the device has been fully demonstrated. Texas Instruments standard warranty applies.

Note:

Predictions show that prototype devices (TMX or TMP) will have a greater failure rate than the standard production devices. Texas Instruments recommends that these devices *not* be used in any production system because their expected end-use failure rate is still undefined. Only qualified production devices are to be used.

TI device nomenclature also includes a suffix with the device family name. This suffix indicates the package type (for example, N, FN, or GB) and temperature range (for example, L). Figure K–1 provides a legend for reading the complete device name for any TMS320 family member.

Figure K–1. TMS320 Device Nomenclature

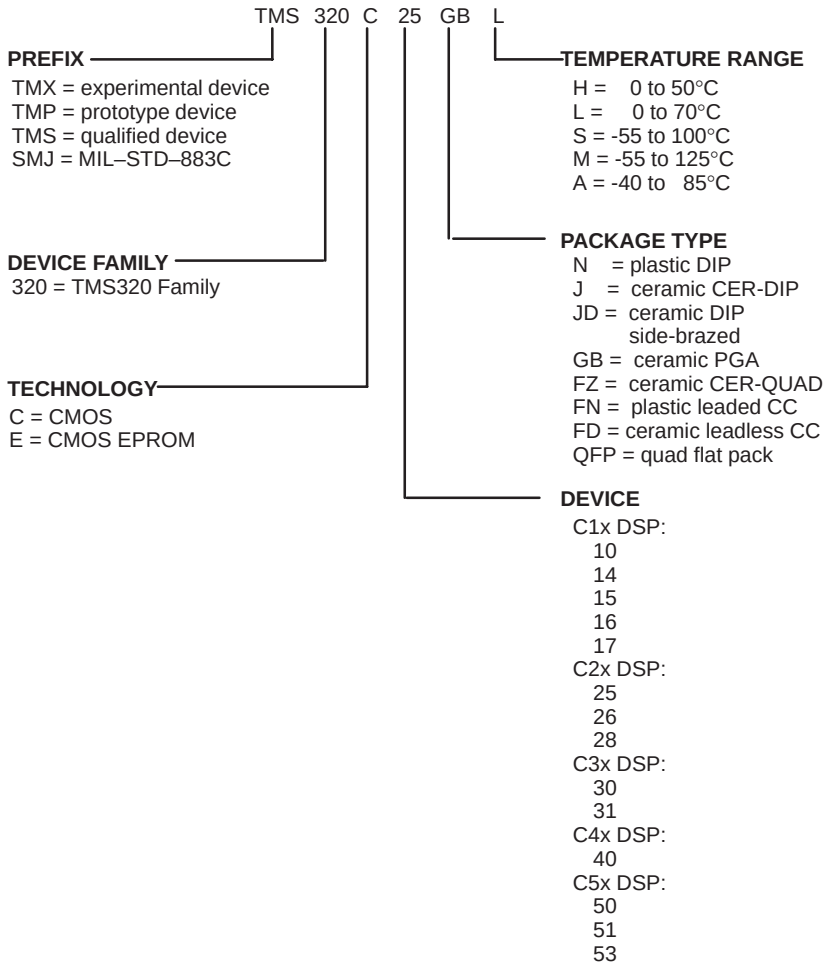
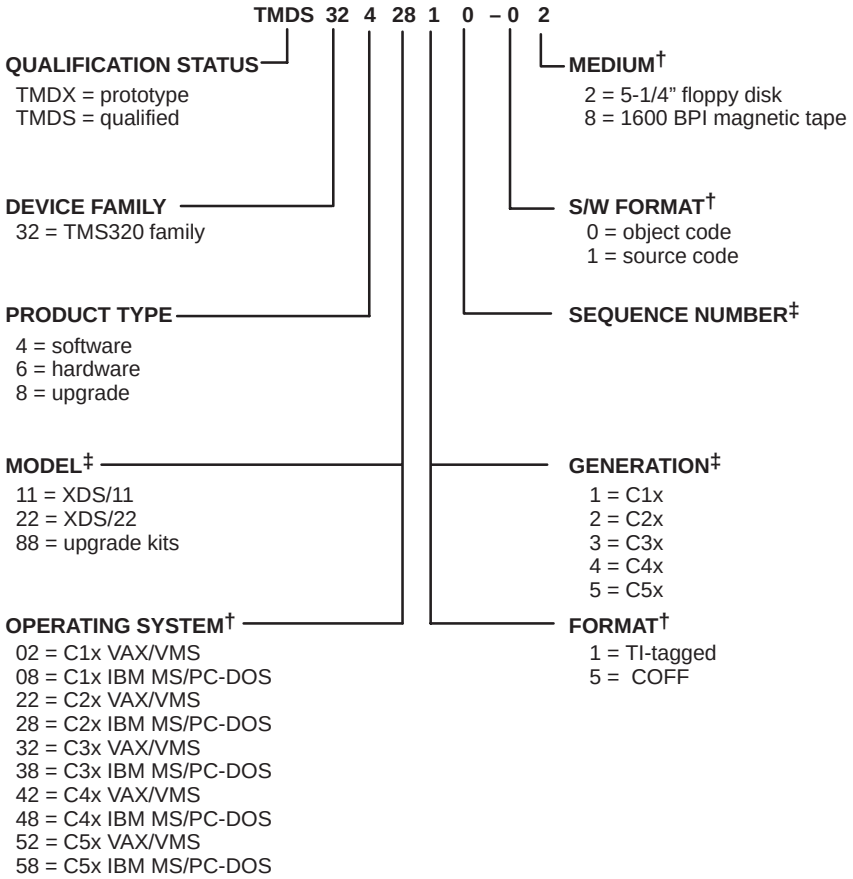


Figure K–2 provides a legend for reading the part number for any TMS320 hardware or software development tool.

Figure K–2. TMS320 Development Tool Nomenclature



† Software only.
‡ Hardware only.

Index

A

A/D interface, 6-43–6-45

A-law, 5-68

ABS, 4-23

ACC, 3-9

accumulator, 3-9, 3-30
  carry bit, 3-31

adapter socket. *See* EPROM programmer

adaptive filtering, 5-71

ADD, 4-25

ADDC, 4-27

ADDH, 4-29

addition, 3-31
  'C25 and 'C26, 5-64

ADDK, 4-9, 4-31

address bus, 3-9

address bus (A15–A0), 2-4

addressing modes, 3-25, 3-26
  direct, 3-25
  indirect, 3-25

ADDS, 4-32

ADDT, 4-34

ADLK, 4-9, 4-36

ADRK, 4-9, 4-37

ADTV, G-18

AFB, 3-9

AIB2, K-1

ALU, 3-9, 3-30

analog converters, H-2

analog interface peripherals
  advanced digital applications, G-18–G-20
    audio/video analog/digital interface devices, G-20
    digital audio, G-19
    video signal processing, G-19
  applications, G-1–G-20
  disk drive applications, G-12–G-14
  modem applications, G-15–G-17
    data converters, G-15
  multimedia, G-2–G-4
    modem communication, G-3
    related devices, G-4
    speech encoding, G-3
    system design consideration, G-2
  servo control, G-12–G-14
    related devices, G-13
  speech synthesis, G-10
    development tools, G-11
    memory, G-10
    voice synthesizers, G-10
  telecommunications, G-5–G-9
    general applications, G-9
    related devices, G-7
    telecom devices, G-8

AND, 4-38

ANDK, 4-9, 4-40

APAC, 4-41

application-oriented operations, 5-68
  adaptive filtering, 5-71–5-76
  bit-reversed addressing, 5-77
  companding, 5-68
  fast Fourier transforms, 5-75–5-81
  FFT inputs and outputs, 5-76
  FFT macros, 5-79
  FIR/IIR filters, 5-70
  PID control, 5-82

applications, 1-8

AR, 3-9, 3-24

ARAU, 3-9

ARB, 3-9

architectural overview, 3-2
  arithmetic logic unit (ALU), 3-3
  diagram, 3-3
  direct memory access, 3-5
  memory interface, 3-4
  multiplier, 3-3
  multiprocessing, 3-4
  on-chip memory, 3-2
  serial port, 3-4

architecture, 3-1

arithmetic logic unit (ALU), 3-3, 3-9, 3-30

arithmetic operations, 5-46–5-67
  division, 5-57–5-59
    using SUBC, 5-57–5-59
  extended-precision arithmetic, 5-62–5-67
    addition, 5-64
    multiplication, 5-66
    subtraction, 5-65
  floating-point, 5-60–5-62
    denormalization, 5-61
    using LACT, 5-61
    using NORM, 5-61
  indexed addressing, 5-62
  moving data, 5-51
    using MACD, 5-52
  multiplication, 5-53–5-57
    measuring efficiency, 5-55
    using LTA–MPY, 5-54
    using MAC, 5-54
    using SQRA, 5-57
  overflow management, 5-46
  scaling, 5-47
  shifting data, 5-47–5-50
    bit-reversed carry addition, 5-48
    FFT bit reversals, 5-48
    other applications, 5-49

ARP, 3-9

assembly language instructions, 4-1

auxiliary register, arithmetic unit, 3-9

auxiliary registers, 3-9, 3-22–3-25
  bus, 3-9
  pointer, 3-9
  pointer buffer, 3-9

B

B, 4-42
BACC, 4-43
BANZ, 4-44
BBNZ, 4-46, 5-45
BBZ, 4-47, 5-45
BC, 4-48
BGEZ, 4-49
BGZ, 4-50
BIO, 2-5, 4-56
BIOZ, 4-51
BIT, 4-52, 5-44, 5-45
bit manipulation, 5-44
bit-reversed (BR) addressing, 5-77
BITT, 4-54, 5-45
BLEZ, 4-56
BLKD, 3-27, 4-57, 5-33
BLKP, 4-60, 5-33
block B0, 5-38
block diagram
  ’C26, 3-8
  ’C2x, 3-7
block moves, 3-27, 5-33
BLZ, 4-63
BNC, 4-64
BNV, 4-65
BNZ, 4-66
bootloader, 5-6–5-21
  configuration words
    BAUD DETECT, 5-13
    CHECKSUM, 5-10, 5-14
    INTERRUPT, 5-9, 5-14
    PROGRAM LENGTH, 5-9, 5-14
    PROGRAM WORD, 5-10, 5-14
    STATUS, 5-9, 5-13
    SYNCHRONIZATION, 5-10, 5-15
  external memory (EPROM) download, 5-15–5-21
    byte ordering, 5-16
  parallel download, 5-6–5-10
    16-bit transfer sequence, 5-8
    8-bit transfer sequence, 5-8
    BIO–XF handshake example, 5-7
    BIO–XF transfer protocol, 5-7
    configuration words, 5-9, 5-13–5-15
    program length, 5-9

bootloader (continued), 5-6–5-21
  serial download, 5-11–5-15
    program length, 5-14
    RS232 serial link, 5-11
    RS232 transfer protocol, 5-12
    RS232 transfer sequence, 5-13
  software listing, 5-17–5-21
  types of download, 5-6
BR, 2-5
branches, 3-32
BV, 4-67
byte mode, DRR operation, 3-69
BZ, 4-68

C

CAL, 5-22
CALA, 4-69, 5-22
CALL, 4-71
CALU, 3-28
  components of, 3-28–3-34
central arithmetic logic unit (CALU), 3-9, 3-28
  ALU and accumulator, 3-30
  components of, 3-28–3-34
  diagram, 3-29
  multiplier, 3-32
  scaling shifter, 3-30
  shift modes, 3-33
  T and P registers, 3-32
CLKOUT1, 2-6, 3-56
CLKOUT2, 2-6, 3-56
CLKR, 2-7
CLKX, 2-7
clock divider, ’C25, 5-26
clock phases, 3-56
clock timing, 3-56
CMPL, 4-73
CMPR, 4-74
CNFD, 4-75
CNFP, 4-76
code generation tools, K-1
  assembler/linker, K-1
  C compiler, K-1
  digital filter design package, K-1
combo-codec interface, 6-37–6-40
companding, 5-68
comparison of internal RAM, 3-18
computed GOTO, 5-28
CONF, 4-77
configuring on-chip RAM, 5-35–5-37
  diagram, 5-36
  example, 5-37, 5-39
consumer electronics
  advanced digital applications, G-18
  advanced digital television, G-18
  digital audio, G-19
  video signal processing, G-19
context restore, ’C25, 5-31
context save, ’C25, 5-30
context switching, 5-29
continuous mode operation, 3-69–3-74
control circuitry, 6-2
  crystal oscillator, 6-5
  emulator architecture, 6-7–6-10
  powerup reset, 6-2
crystal oscillator circuit, 6-5
crystals, H-4
  frequencies, H-4
  specifications, H-4
  vendors, H-4

D

D/A interface, 6-42
DAB, 3-9
DAC, G-20
data bus, 2-4, 3-9
data bus (D15–D0), 2-4, 3-9
data memory, 3-17
data moves, 3-27, 5-51
data pointer, 3-9
data sheets
  SMJ320C2x, 4-1
  TMS320C25, A-1
  TMS320C26, B-1
  TMS320C28, C-1
  TMS320E25, A-1
debugging tools, K-1
development support, K-1–K-4

development systems, K-1
  analog interface board (AIB2), K-1
  emulator (XDS/22), K-1
  evaluation module (EVM), K-1
  simulator, K-1
development tool nomenclature, K-4
device evolution, K-2
  TMP, K-2
  TMS, K-2
  TMX, K-2
device nomenclature, K-3
digital audio, G-19
DINT, 4-78
direct addressing, 4-2
  diagram, 4-3
direct memory access (DMA), 3-5, 3-75
  See also DMA
DIT, 5-81
division, 5-57–5-59
DMA, 3-75, 6-32
  in a PC environment, 6-34
  master-slave configuration, 6-33
DMOV, 3-27, 4-79
download/bootstrapping mode (’C26).
  See bootloader
DP, 3-9
DR, 2-4, 2-7
DRB, 3-9
DRR, 3-10
DS, 3-16
DSP hotline, ix
DX, 2-7
DXR, 3-10

E

echo cancellation, 6-48
EINT, 4-81
emulator (XDS), 6-7
  bus control, 6-7
  miscellaneous considerations, 6-9
  READY and memory substitution, 6-8
  TMS320C25 designs, 6-9
EPROM, adapter socket, F-2
EPROM programmer, F-2
EPROM programming, F-1
  code protection, F-12–F-15
  data format, F-4
  erasure, F-7
  FAST programming, F-7, F-9
  output disable, F-11
  pin nomenclature, F-5
  program inhibit, F-11
  program verify, F-8
  programming modes, F-6
  programming the RBIT, F-12–F-15
  protect verify, F-15
  RBIT operation, F-14
  RBIT side effects, F-14
  read mode, F-11
  SNAP! pulse programming, F-8, F-10
  timing, F-11
  verification, F-4
  wiring diagram, F-5
EPROMs, 6-22–6-26
EVM, K-1
EXAMPLE, 4-19
extended-precision arithmetic, 5-62–5-67
  addition, 5-64
  multiplication, 5-66
  subtraction, 5-65
external memory interface, 3-54–3-58
  clock timing, 3-56
  I/O pins, 3-56
  memory combinations, 3-54
external program/data access, 3-47

F

fast Fourier transforms (FFT), 5-75
FAST programming, F-7
  flowchart, F-9
FFT, 5-81
FFT macros, 5-79
FFT requirements, 5-81
filtering, 5-70
FIR filters, 5-70
floating-point arithmetic, 5-60
  denormalization, 5-61
  using LACT, 5-61
  using NORM, 5-61
floating-point multiply, ’C25, 5-61
FORT, 4-82

Fourier transforms, 5-75
framing control, 3-67
FSR, 2-7
FSX, 2-7
functional block diagram, 3-6–3-8

G

gates, J-5
global memory, 3-76, 6-35
  access timing, 3-77
  communication, 6-36
  configurations, 3-77
global memory allocation register (GREG), 3-77
global register, 3-9
graphics and image processing, 6-50
GREG, 3-9, 3-77
ground pin, 2-6

H

hardware applications, 6-1
  direct memory access (DMA), 6-32–6-34
  global memory, 6-35
  interfacing memories, 6-11–6-30
  interfacing peripherals, 6-37–6-47
  system applications, 6-48–6-52
Harvard architecture, 3-2
HOLD, 2-5, 3-46, 3-78, 6-9
hold function, 3-78
hold operation, 3-46
hold timing, 3-80
HOLDA, 2-5, 3-46, 3-78, 6-9
hotline, ix

I

I/O
  addressing, 6-46
  pins, 3-56
  ports, 6-46
  processor communication, 6-47
IACK, 2-5
IDLE, 4-83
IIR filters, 5-70
immediate addressing, 4-8–4-10
IMR, 3-10, 3-60
IN, 4-84, 5-34
indexed addressing, 5-62
indirect addressing, 4-4–4-8
  arithmetic operations, 4-6
  bit fields, 4-7
  diagram, 4-4
  format examples, 4-8
  symbols used, 4-5
  types of, 4-5
initialization, 5-2
  ’C25, 5-3
  ’C26, 5-4
  examples, 5-3–5-5
  processor configuration, 5-2
  TMS320C26, download/bootstrapping mode. *See* bootloader
instruction cycle timings, ’C25, 5-2
instruction register, 3-10
instruction set, 4-11
  example, 4-19–4-22
  ABS, 4-23
  ADD, 4-25
  ADDC, 4-27
  ADDH, 4-29
  ADDK, 4-31
  ADDS, 4-32
  ADDT, 4-34
  ADLK, 4-36
  ADRK, 4-37
  AND, 4-38
  ANDK, 4-40
  APAC, 4-41
  B, 4-42
  BACC, 4-43
  BANZ, 4-44
  BBNZ, 4-46
  BBZ, 4-47
  BC, 4-48
  BGEZ, 4-49
  BGZ, 4-50
  BIOZ, 4-51
  BIT, 4-52
  BITT, 4-54
  BLEZ, 4-56
  BLKD, 4-57
  BLKP, 4-60
  BLZ, 4-63

instruction set (continued), 4-11
BNC, 4-64
BNV, 4-65
BNZ, 4-66
BV, 4-67
BZ, 4-68
CALA, 4-69
CALL, 4-71
CMPL, 4-73
CMPR, 4-74
CNFD, 4-75
CNFP, 4-76
CONF, 4-77
DINT, 4-78
DMOV, 4-79
EINT, 4-81
FORT, 4-82
IDLE, 4-83
IN, 4-84
LAC, 4-85
LACK, 4-86
LACT, 4-87
LALK, 4-89
LAR, 4-90
LARK, 4-92
LARP, 4-93
LDP, 4-94
LDPK, 4-95
LPH, 4-96
LRLK, 4-97
LST, 4-98
LST1, 4-100
LT, 4-103
LTA, 4-104
LTD, 4-106
LTP, 4-108
LTS, 4-109
MAC, 4-111
MACD, 4-114
MAR, 4-117
MPY, 4-119
MPYA, 4-120
MPYK, 4-121
MPYS, 4-122
MPYU, 4-123
NEG, 4-125
NOP, 4-126
NORM, 4-127
OR, 4-129
ORK, 4-130
instruction set (continued), 4-11
OUT, 4-131
PAC, 4-132
POP, 4-133
POPD, 4-134
PSHD, 4-135
PUSH, 4-136
RC, 4-137
RET, 4-138
RFSM, 4-139
RHM, 4-140
ROL, 4-141
ROR, 4-142
ROVM, 4-143
RPT, 4-144
RPTK, 4-145
RSXM, 4-146
RTC, 4-147
RTXM, 4-148
RXF, 4-149
SACH, 4-150
SACL, 4-151
SAR, 4-152
SBLK, 4-154
SBRK, 4-155
SC, 4-156
SFL, 4-157
SFR, 4-158
SFSM, 4-159
SHM, 4-160
SOVM, 4-161
SPAC, 4-162
SPH, 4-163
SPL, 4-164
SPM, 4-165
SQRA, 4-166
SQRS, 4-167
SST, 4-168
SST1, 4-170
SSXM, 4-172
STC, 4-173
STXM, 4-174
SUB, 4-175
SUBB, 4-176
SUBC, 4-177
SUBH, 4-179
SUBK, 4-180
SUBS, 4-181
SUBT, 4-182
SXF, 4-183

instruction set (continued), 4-11
TBLR, 4-184
TBLW, 4-186
TRAP, 4-188
XOR, 4-189
XORK, 4-190
ZAC, 4-191
ZALH, 4-192
ZALR, 4-193
ZALS, 4-194
instruction set summary, 4-13–4-17
special groups, 4-13
instructions
accumulator, 4-14
auxiliary register/page pointer, 4-15
branch/call, 4-16
control, 4-17
I/O and memory, 4-16
individual descriptions, 4-18–4-194
register and multiply, 4-15
instrumentation, 6-51
interface
AIC, 6-40–6-42
analog-to-digital (A/D), 6-43–6-45
combo-codec, 6-37–6-40
digital-to-analog (D/A), 6-42
interface timing analysis, 6-29–6-31
interfacing memories, 6-11
EPROMs, 6-22–6-26
port, buses, and control signals, 6-11
PROMs, 6-12–6-19
read and write cycles, 6-12
SRAMs, 6-26–6-29
timing analysis, 6-29–6-31
wait-state generator, 6-19
interfacing peripherals, 6-37
interfacing PROMs, address decoding, 6-12–6-19
internal hardware, 3-9–3-11
interrupt, flag register, 3-10
interrupt acknowledge, 2-5
interrupt mask register, 3-10
interrupt mask register (IMR), 3-60
interrupt service routine (ISR), 5-29–5-32
interrupts, 2-5, 3-46, 3-59–3-62
external interface, 3-60
locations, 3-59
logic diagram, 3-61
operation, 3-59
priorities, 3-59, 5-32
timing diagram, 3-62
IR, 3-10
IS, 2-4

K

key features, 1-6

L

LAC, 4-85
LACK, 4-9, 4-86
LACT, 4-87
LALK, 4-9, 4-89
LAR, 4-90
LARK, 4-9, 4-92
LARP, 4-93
LC circuit, 6-5
LDP, 4-94
LDPK, 4-9, 4-95
Literature Response Center, ix
logical and arithmetic operations, 5-43
long immediate addressing, 4-10
LPH, 4-96
LRLK, 4-9, 4-97
LST, 4-98
LST1, 4-100
LT, 4-103
LTA, 4-104, 5-54
LTD, 4-106
LTP, 4-108
LTS, 4-109

M

μ-law, 5-68
MAC, 4-111
MACD, 4-114
MACD operation, 5-52
MAR, 4-117
masked parts, I-1
MCS, 3-10
memories, H-2
memory
  ’C26 maps, 3-16, 3-20
  ’C2x maps, 3-15, 3-19
  addressing modes, 4-2
  blocks, 3-12, 3-16, 3-17
  combinations, 3-54
  data, 3-12
  DMA, 3-5
  global, 3-76
  interface, 3-4
  management, 5-33
  organization, 3-12
  program, 3-12
memory organization, 3-12
  data memory, 3-12
  memory maps, 3-15
  program memory, 3-12–3-14
    ’C26 diagram, 3-14
    ’C2x diagram, 3-13
memory-mapped registers, 3-22
microcall stack, 3-10
microcall stack (MCS) register, 3-36
microcomputer mode, 2-5
microprocessor mode, 2-5
military data sheets, D-1
modem, 6-48
modem applications, G-15
  data converters, G-15
MP/MC, 2-5
MPY, 4-119, 5-54
MPYA, 4-120
MPYK, 4-9, 4-121
MPYS, 4-122
MPYU, 4-123
MSC, 2-6
MULT, 3-10
multimedia applications, G-2
  multimedia-related devices, G-8
multiplexed external data bus, 3-42
multiplication, 5-53–5-57
  ’C25, 5-66
multiplier, 3-3, 3-10, 3-32
multiprocessing, 3-75–3-81
  global memory, 3-76
  hold function, 3-78–3-81
  synchronization, 3-75

N

NEG, 4-125
NOP, 4-126
NORM, 4-127
numeric processing, 6-51

O

on-chip EPROM, 3-12
on-chip memory, 3-2
on-chip program access, 3-46
on-chip program execution, example, 5-41
on-chip RAM, 3-12
  configuration, 5-35–5-37
  configuration diagram, 5-36
  program execution, 5-38
on-chip ROM, 3-12, I-1
OR, 4-129
ORK, 4-9, 4-130
oscillator circuit
  diagram, 6-5
  LC circuit, 6-5
  magnitude of impedance, 6-6
OUT, 4-131, 5-35
overflow management, 5-46

P

P, 3-10
P register (PR), 3-32
PAB, 3-10
PAC, 4-132
PC, 3-10
period register, 3-10

PFC, 3-10
PIC, ix
PID control, 5-82
pin assignments, 2-2
pinouts, 2-1
pipeline hardware, 3-45
pipeline operation, 3-37–3-47
  ADD followed by SACL, 3-41
  branch to on-chip RAM, 3-44
  'C25, 3-39
  decode, 3-37
  execute, 3-37
  fetch, 3-37
  instruction sequence, 3-40
  prefetch, 3-37
  RET from on-chip RAM, 3-45
  three-level, 3-38
  two-level, 3-38
  wait states, 3-41
  with external data bus conflict, 3-43
PLCC/CLCC adapter socket, F-2
POP, 4-133
POPD, 4-134
powerdown modes ('C25), 3-53
powerup reset, 6-2–6-4
PR, 3-10
PRD, 3-10
prefetch counter, 3-10
processors overview, 1-4
Product Information Center, ix
product register, 3-10
program bus, 3-10
program control, 5-22
program counter (PC), 3-10, 3-35, 3-43
program execution, 5-38
program memory, 3-17
  address bus, 3-10
program verify, F-8
PS, 2-4
PSHD, 4-135
pulse programming, F-8
PUSH, 4-136

Q

QIR, 3-10
quality and reliability, J-1–J-5
queue instruction register, 3-10

R

R/W, 2-5
RAM(B0), 3-10
RAM(B1), 3-10
random access memory
  data only, 3-10
  data or program, 3-10
RBIT, F-12
RC, 4-137
read only memory, 3-10
READY, 2-4
registers
  auxiliary, 3-22
  DRR, 3-64
  DXR, 3-64
  indirect addressing, 3-23
  memory-mapped, 3-22
  serial port, 3-63
reliability stress tests, J-2
  microcontroller tests, J-5
  microprocessor tests, J-5
  test environments, J-2
  types of tests, J-3
repeat counter, 3-10
repeat counter (RPTC), 3-53
reset, 2-6, 3-46, 3-47
reset circuit, 6-2–6-4
  diagram, 6-3
RET, 4-138
RFSM, 4-139
RHM, 4-140
robotics, 6-51
ROL, 4-141
ROM, 3-10
ROM code flowchart, I-2
ROM code media, I-3
ROM codes, I-1–I-3
ROM protect bit, F-12
ROR, 4-142

ROVM, 4-143
RPT, 4-144, 5-27
RPTC, 3-10
RPTK, 4-9, 4-145
RS, 2-6
RSR, 3-11
RSXM, 4-146
RTC, 4-147
RTXM, 4-148
RXF, 4-149

S

SACH, 4-150
SACL, 4-151
SAR, 4-152
SBLK, 4-9, 4-154
SBRK, 4-9, 4-155
SC, 4-156
scaling, 5-47
scaling shifter, 3-30
second generation devices, 1-2
serial port, 3-4, 3-63–3-74
  block diagram, 3-65
  burst mode, 3-68
  continuous mode, 3-69–3-74
  data receive register, 3-10
  data transmit register, 3-10
  framing, 3-67
  receive timing diagram, 3-67
  registers, 3-63
  shift register, 3-11
  timing, 3-67
  transmit and receive, 3-65–3-67, 3-68, 3-70
  transmit shift register, 3-11
  transmit timing diagram, 3-66
servo control/disk drive applications, G-12
servo control-related devices, G-13
SFL, 4-157
SFR, 4-158
SFSM, 4-159
shift modes, 3-33
shifters, 3-11
shifting data, 5-47–5-50
SHM, 4-160
short immediate addressing, 4-9
signal descriptions, 2-4–2-7
single-instruction loops, 5-26
SMJ320C2x, data sheets, D-1
SNAP! pulse programming, F-8
  flowchart, F-10
sockets, H-3
software stack, 5-24
software stack expansion, 5-24
SOVM, 4-161
SPAC, 4-162
speech
  development tools, G-11
  memories, G-10
  synthesis applications, G-10
SPH, 4-163
SPL, 4-164
SPM, 4-165
SQRA, 4-166, 5-57
SQRS, 4-167
SST, 4-168
SST1, 4-170
SSXM, 4-172
ST0, 3-11, 3-49
ST1, 3-11, 3-49
stack, 3-11, 3-35
static RAMs, 6-26–6-29
status registers, 3-49
  data processing, 5-43
  field definitions, 3-50
  temporary register, 3-11
STC, 4-173
STRB, 2-5
STXM, 4-174
SUB, 4-175
SUBB, 4-176
SUBC, 4-177
  fractional division, 5-59
  integer division, 5-59
SUBH, 4-179
SUBK, 4-9, 4-180
subroutines, 5-22
  example, 5-22
SUBS, 4-181
SUBT, 4-182

supply voltage pin, 2-6
support tool evolution
  TMDS, K-2
  TMDX, K-2
support tools nomenclature, K-2
SXF, 4-183
symbols, 3-10
symbols and abbreviations, 4-11–4-13
SYNC, 2-5, 3-75
synchronization, 3-75
  timing ('C25), 3-76
system applications, 6-48
  echo cancellation, 6-48
  graphics and image processing, 6-50
  high-speed control, 6-51
  instrumentation, 6-51
  modem, 6-48
  numeric processing, 6-51
  voice coding, 6-49
system control, 3-35–3-53
  See also control circuitry
  'C25 powerdown modes, 3-53
  diagram, 3-35
  hardware stack, 3-35
  pipeline operation, 3-37–3-47
  program counter, 3-35
  repeat counter, 3-53
  reset, 3-47
  status registers, 3-49–3-52
  timer, 3-52

T

T register (TR), 3-32
TBLR, 4-184, 5-34
TBLW, 4-186, 5-34
telecom devices, G-8
telecommunications applications, G-5
  DSP/combo, G-6
temporary register, 3-11
TIM, 3-11
TIM register, 3-52
timer, 3-11, 5-25
timer block diagram, 3-52
timer operation, 3-52
timing
  BIO, 3-57
  external flag (XF), 3-58
  memory, 3-80
timing control, 3-67
TLC32046, G-3
TLC32070, G-14
TMS320C25, 1-4
  data sheets, A-1
TMS320C25-33, 1-4
TMS320C25-50, 1-4
TMS320C26, 1-4
  data sheet, B-1
TMS320C26 block diagram, 3-8
TMS320C26 description,
TMS320C28, 1-1–1-7, 2-3,
  data sheet, C-1
TMS320C2x, instruction cycle timings, E-2
TMS320C2x block diagram, 3-7
TMS320E25, 1-4
TR, 3-11
transistors, J-5
TRAP, 4-188
two-word instructions, 3-43

U

user design considerations, 6-7–6-10

V

VCC, 2-6
video signal processing, G-19
voice coding, 6-49
voice synthesizers, G-10
VSS, 2-6

W

wait-state generator, 6-19
  design, 6-21
  memory/peripheral access, 6-20
  timing, 6-22

X

X1, 2-6
X2/CLKIN, 2-6
XDS/22, K-1
XF, 2-6, 3-56
XOR, 4-189
XORK, 4-9, 4-190
XSR, 3-11

Z

ZAC, 4-191
ZALH, 4-192
ZALR, 4-193
ZALS, 4-194

IMPORTANT NOTICE

Texas Instruments (TI) reserves the right to make changes to its products or to discontinue any semiconductor product or service without notice, and advises its customers to obtain the latest version of relevant information to verify, before placing orders, that the information being relied on is current.

TI warrants performance of its semiconductor products and related software to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Certain applications using semiconductor products may involve potential risks of death, personal injury, or severe property or environmental damage ("Critical Applications").

TI SEMICONDUCTOR PRODUCTS ARE NOT DESIGNED, INTENDED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE-SUPPORT APPLICATIONS, DEVICES OR SYSTEMS OR OTHER CRITICAL APPLICATIONS.

Inclusion of TI products in such applications is understood to be fully at the risk of the customer. Use of TI products in such applications requires the written approval of an appropriate TI officer. Questions concerning potential risk applications should be directed to TI through a local SC sales office.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards should be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein. Nor does TI warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used.

Copyright © 1997, Texas Instruments Incorporated